20030228021

AL/EQ-TR-1993-0018

AD-A276 879

PETROLEUM HYDROCARBON THICKNESS IN GROUNDWATER AN ANALYSIS OF FIELD DATA

ARMSTRONG LABORATORY

Daniel A. Turek

ENVIRONICS DIRECTORATE
139 Barnes Drive, Suite 2
Tyndall AFB FL 32403-5323

August 1993

Final Technical Report for Period January 1991 - December 1991

Approved for public release; distribution unlimited.

AIR FORCE MATERIEL COMMAND
TYNDALL AIR FORCE BASE, FLORIDA 32403-5323

NOTICES

This report has been reviewed and is approved for publication.

Bruce J Nielsen

BRUCE J NIELSEN
Project Officer

Michael G. Katona

MICHAEL G. KATONA, Ph D.
Chief Scientist,
Environics Directorate

Robert G. LaPoe

ROBERT G. LaPOE, Maj, USAF
Chief, Site Remediation
R&D Division

Neil J. Lamb.

NEIL J. LAMB, Col, USAF
Director,
Environics Directorate

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
August 1993

3. REPORT TYPE AND DATES COVERED
Thesis Jan - Dec 1991

4. TITLE AND SUBTITLE
PETROLEUM HYDROCARBON THICKNESS IN GROUNDWATER
AN ANALYSIS OF FIELD DATA

5. FUNDING NUMBERS

6. AUTHOR(S)
MR DANIEL A. TUREK

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ARMSTRONG LABORATORY/ENVIRONICS DIRECTORATE
139 BARNES DRIVE, SUITE 2
TYNDALL AFB, FL 32403-5323

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL/EQ-TR-1993-0018

11. SUPPLEMENTARY NOTES
BRUCE J. NIELSEN, 904-283-6011, DSN 523-6011

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Fuel contamination of the subsurface environment can exist in as many as three phases. First, there will exist a soluble phase resulting from chemical components in the fuel such as benzene, toluene, and xylene dissolving into the ground water and becoming transported by it. Another is the residual phase consisting of immobile fuel contained within the pore spaces of the vadoze zone above the water table. Finally, there is a free-fuel phase that is a mobile liquid that can spread out over the water table and generally follows its flow path. It is the measurement and estimation of this phase's thickness that is the main subject of this project. The objectives of this project were to compare three methods of estimating the actual free-fuel product volume in the unsaturated zone of ground water. This project was unique in that the volume estimates were meade of six actual sites where JP-4 jet fuel exists on the aquifer, rather than using laboratory conditions.

14. SUBJECT TERMS
FUEL CONTAMINATION, JP-4 JET FUEL, PETROLEUM HYDROCARBON, JP-4 THICKNESS ESTIMATES

15. NUMBER OF PAGES
283

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

(The reverse of this page is blank.)

PREFACE

This report was submitted as a thesis to The Graduate School at the University of Alabama at Birmingham in partial fulfillment for the degree of Master of Science in Public Health. The thesis covers work performed by Mr. Daniel A. Turek. The effort was partially funded by the Air Force Civil Engineering Laboratory, now the Armstrong Laboratory Environmental Quality Directorate.

This thesis is being published in its original format by this agency because of its interest to the worldwide scientific and engineering community. The AL/EQW Project Officer is Bruce J. Nielsen.

This report has been reviewed by the Public Affairs Officer (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

Accession For	
NTIS GRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

EXECUTIVE SUMMARY

Fuel contamination of the subsurface environment can exist in as many as three phases. First, there will exist a soluble phase resulting from chemical components in the fuel such as benzene, toluene, and xylene dissolving into the ground water and becoming transported by it. Another is the residual phase consisting of immobile fuel contained within the pore spaces of the vadose zone above the water table. Finally, there is a free-fuel phase that is a mobile liquid that can spread out over the water table and generally follows its flow path. It is the measurement and estimation of this phase's thickness that is the main subject of this project.

The objectives of this project were to compare three methods of estimating the actual free-fuel product volume in the unsaturated zone of ground water. This project was unique in that the volume estimates were made of six actual sites where JP-4 jet fuel exists on the aquifer, rather than using laboratory conditions.

Three equations were used in this project to estimate the actual product thickness on the aquifer. The first equation, Concawe, presented in 1979 assumes a linear relationship between oil, water and air capillary pressures at their interface. The relationship is known as the Concawe factor and equals 3.34 for JP-4 at a density of 0.77 g/cm^3. The Concawe equation is simple to use and requires no knowledge of the aquifer. The Farr equation, published in 1990, estimates the fuel volume on the aquifer with knowledge and consideration of the pertinent soil properties, i.e. porosity, particle size distribution, and saturation data. Calculated fuel thickness depends only on the difference of the fluid levels of fuel and water in the monitoring well. The Air Force (AF) formula developed by AFESC, uses the same input parameters as Farr, with the deletion of the saturation data. However the AF equation answer is dependent upon the fluid levels in the well relative to ground surface.

The observed levels of JP-4 in twenty-one wells at six sites were included in this study. The thickness levels of fuel on the aquifer were calculated using the Farr, AF, and Concawe equations using the low, average, and high JP-4 readings. On seven of the wells intensive calculations were performed to examine the impact of varying porosity and oil-water surface tension on calculated JP-4 thickness.

The Concawe equation as expected produced a linear relationship between observed and calculated JP-4 thickness data. The Farr and AF equations produced estimates that were generally within 50% of each other. The affect of changing oil-water surface tension was consistent in that lower values produced a greater calculated JP-4 thickness value. The calculated JP-4 thicknesses increased from 50 to 200% based on decreasing the oil-water surface tension from 20 to 5 dynes/cm. The effect of larger porosity values also increased the calculated JP-4 thickness on a linear basis, with only one exception. The calculated JP-4 thickness increased by an average of 80% when the porosity was increased from 0.25 to 0.45.

Actual JP-4 thickness estimates were calculated using the AF and Farr equations, however it is the authors opinion the answers lack reliability due to the deficiency of site-specific particle size distribution data. For the majority of wells, the particle size distributions were determined by interpreting well logs and assigning the appropriate distribution fractions from standard geologic references. Also, actual site porosities were unknown, therefore porosity was assigned based on published values of similar soil types. When site parameters of porosity, oil-water surface tension, and particle size distribution are unknown, the Concawe equation is recommended for use. The Farr and AF equations require input parameters tailored specifically to the location under investigation. Using generic soil property values in the two equations results in generating a wide range answers subject to interpretation.

TABLE OF CONTENTS

LIST OF TABLES

PETROLEUM HYDROCARBON THICKNESS IN GROUNDWATER
AN ANALYSIS OF FIELD DATA

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF SYMBOLS

g	magnitude of gravity force per unit volume
p	fluid pressure
P_c	capillary pressure
P_d	displacement pressure
S	saturation
S_e	effective saturation
S_r	residual saturation
λ	empirical exponent used as index of pore size distribution
ρ	fluid density
σ	interfacial tension
ϕ	porosity
cm	centimeter
D	depth below ground surface
h_d	air entry capillary head (Brooks-Corey model)

SUPERSCRIPTS AND SUBSCRIPTS

$_o$	organic (JP-4)
$_w$	water
$_a$	air

NOTICE

This project was conducted as part of research required for fulfillment of the Master of Science in Public Health (MSPH) degree at the University of Alabama at Birmingham, School of Public Health Department of Environmental Health Sciences, and as a field study for the U. S. Air Force, Engineering and Services Center, Environics Division, (USAF AFESC/RDVW) Tyndall AFB FL. Funding for this project was provided by the US Air Force. Any mention of product names in this report does not constitute endorsement by the US Air Force or the University of Alabama at Birmingham.

Daniel R Turek

DANIEL R. TUREK, CAPTAIN, USAF, BSC
Bioenvironmental Engineer
Graduate Student, School of Public Health

John F. Manning Jr.

Advisor
Dr. John F. Manning, Jr.
Assistant Professor and Director of the Hazardous Substance Management Program

(The Reverse of this Page is Blank.)

INTRODUCTION

OBJECTIVE

This research had the following main objective; through field measurements of floating fuel thickness (JP-4 jet fuel) in different aquifer materials, a comparison of existing theoretical methods was made to accurately estimate actual product volume in the unsaturated zone of ground water. Various methods have been proposed which predict and estimate the actual volume of hydrocarbons in porous media from laboratory experiments. Limited field studies have been conducted using the laboratory derived methodologies to assist in validating the actual levels of hydrocarbon (in this case, JP-4) found in various soil formations. This research project applied three formulas currently available in an attempt to predict the actual volume of JP-4 in a porous soil formation from the apparent thickness of JP-4 measured over time in monitoring wells. This project was unique in that actual JP-4 contaminated field sites were used for the study, whereas the majority of the published research in this area has been limited to laboratory bench-scale or pilot scale testing of the existing methodologies and formulas. The theory is based on knowledge of fundamental soil properties such as porosity, saturation factors, grain size distributions and pertinent physical properties of JP-4.

Presently, there is no verified widely-used method for predicting the relationship between monitoring well petroleum product thickness and actual thickness of hydrocarbon in the soil. The contamination of groundwater and vadose zone soils by petroleum products is a widespread problem affecting municipal and military airports, oil refineries, large and small oil distribution centers including the corner gas station (Figure 1). The presence of JP-4 in or on the groundwater is often manifested by the occurrence of JP-4 in monitoring wells.

An accurate estimate of the volume of free product available needs to be obtained to aid in the design of the pumping, storage and handling systems required in the initial cleanup effort (Figure 2). The initial cleanup effort usually encompasses the removal of the free floating layer of fuel, followed by various remedial actions to remove the residual (trapped) fuel from the soil. Using the observed level (uncorrected) of fuel found in a monitoring well in the volume estimate usually overestimates the recoverable product volume at most sites. This may lead to over design of recovery facilities and lagging doubts over the effectiveness of the recovery systems. However no references or case studies were found where the fuel recovery system was "over-designed".

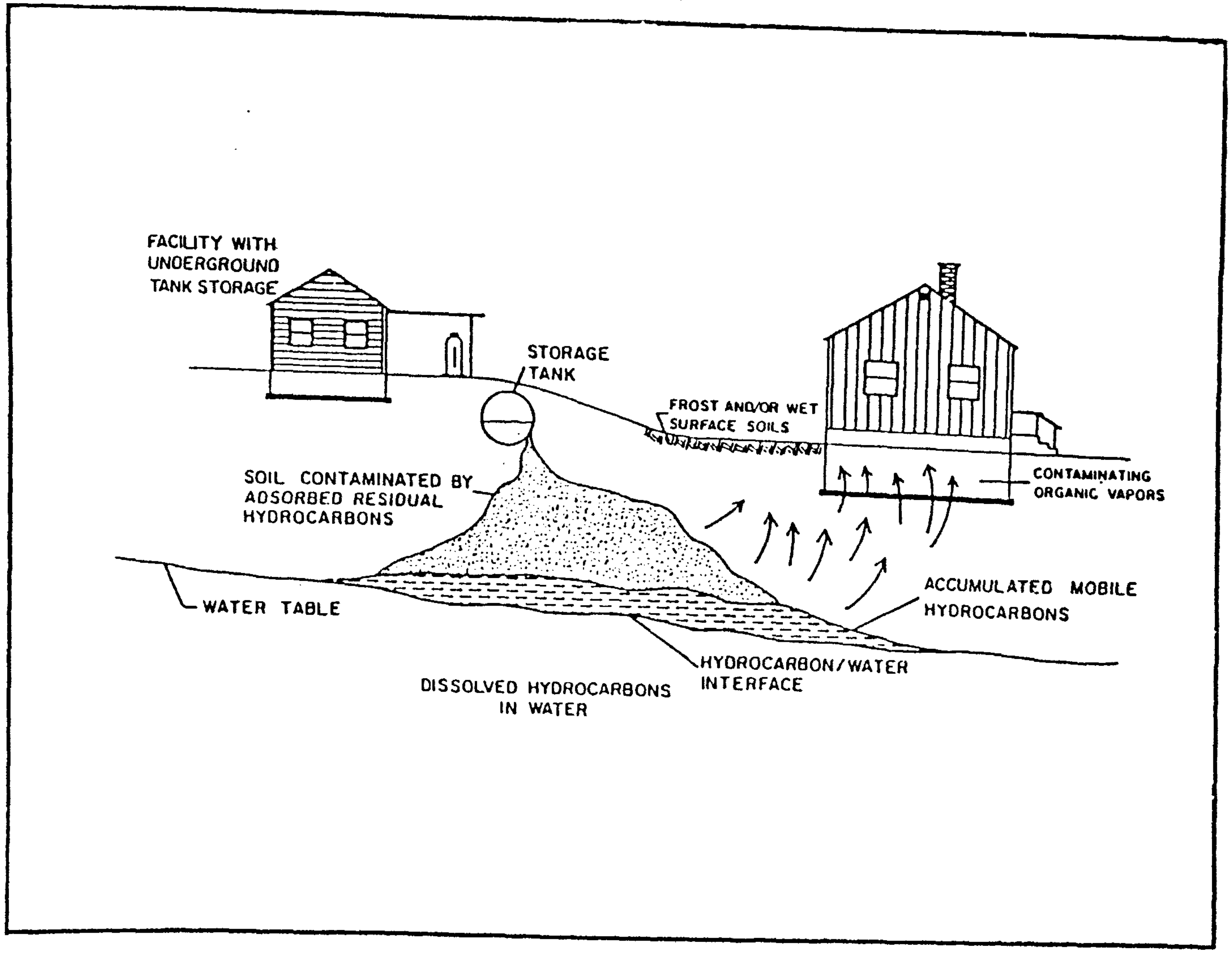


FIGURE 1 TYPICAL IMPACTS FROM SUBSURFACE LEAKS FROM: YANIGA, 1984

FROM: HOMESTEAD AFB 1988 IRP REPORT

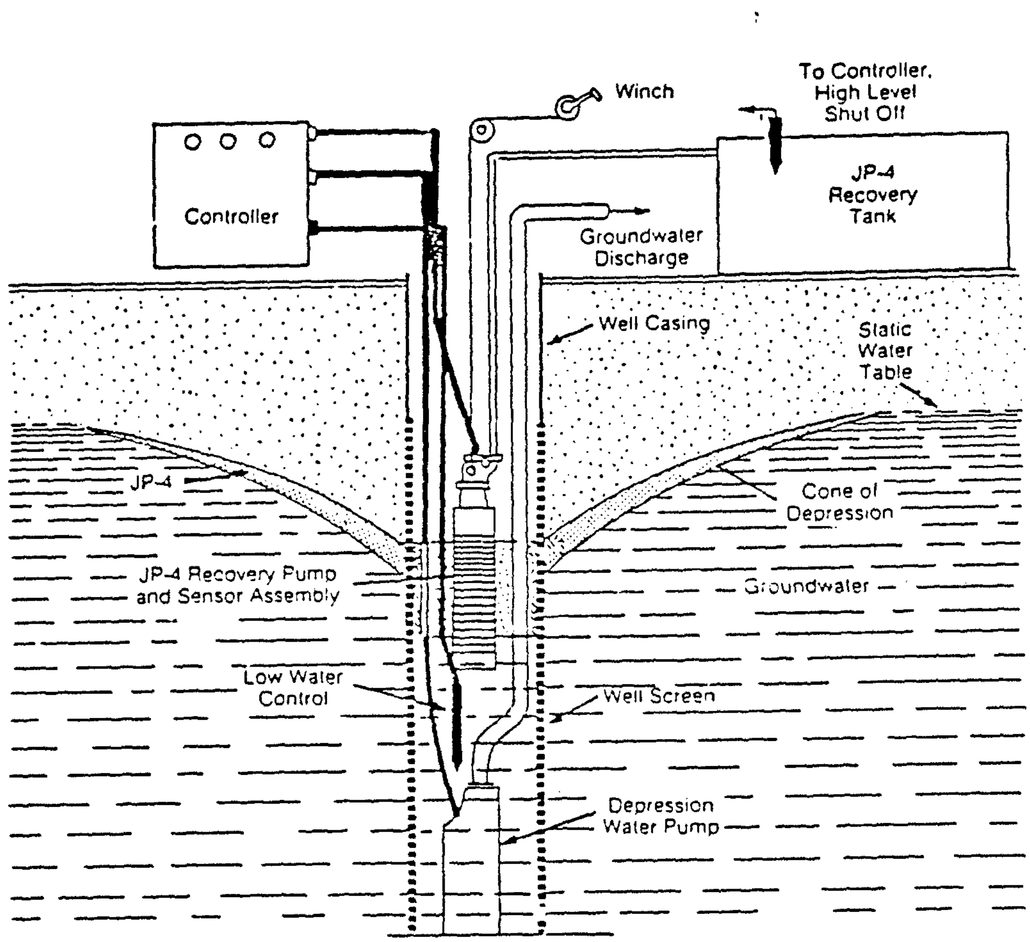


FIGURE 2 TYPICAL JP-4 RECOVERY WELL

JP-4 fuel can exist in three phases at a given location: 1) A soluble phase where chemical components of the fuel, such as benzene, toluene, and xylene, dissolve into the groundwater and become transported by it. 2) A residual phase consisting of immobile fuel trapped in the unsaturated pore spaces of the aquifer vadose zone above (possibly below) the water table (known as the fuel capillary fringe) and 3) a free-fuel phase which is a mobile liquid floating on top of the water table. Current understanding of the fuel capillary fringe is best described using either the Brooks-Corey (BC) or van Genuchten (VG) equations utilizing a three phase equilibrium model of the system (Corey 1986, van Genuchten 1980). The condition of static equilibrium is crucial. The Brooks-Corey method was chosen for this project as it was a common factor in two of the three equations used to estimate actual fuel thickness. Together with observed fluid levels in monitoring wells, it permits calculation of the spatial distributions of fuel-water and air-fuel capillary pressures in the porous medium (Corey 1986). Then prescribed functions relating fluid contents and capillary pressures can be translated directly to spatial distributions of fluid content. Finally, vertical integration of the fuel content yields the volume of fuel in the porous medium per unit area (Farr et al. 1990).

JP-4 TOXICITY

JP-4 is a complex mixture of aliphatic and aromatic hydrocarbon compounds defined in terms of physical and chemical characteristics, including various additives all of which meet the requirements of Military Specification MIL-T-5624L. The fuel contains over 300 different hydrocarbon compounds plus components used to control oxidation, inhibit corrosion and icing, and to passivate metal fuel system elements. Major components of JP-4 are: (by weight) methyl butane 12.2%, n-pentane 13%, methyl pentane 11.3%, n-hexane 8.1%, n-butane 5.6%, toluene 2.7%, and benzene 1.2%. As indicated, JP-4 is primarily aliphatic hydrocarbons (paraffins) with an average concentration of 10-11% aromatics and 1% unsaturated hydrocarbons. As a class, paraffins are generally considered to be central nervous system (CNS) depressants with the exception of the first three members of the series, methane, ethane, and propane, which are simple asphyxiants and n-hexane which is a peripheral neuropathic agent. In water, a concentration of 500 mg/l JP-4 was lethal to fresh water salmon fingerling, however the time period was not specified (Macewen 1984). In Air Force toxicity testing of JP-4, it was determined a concentration of 18.8 ±2 mg/l produced the 96 hour LC_{50} in the fat head minnow. (Dismukes, 1986). Other researchers have revealed a 96-hour LC_{50} of 3.8 mg/l for golden shiners,

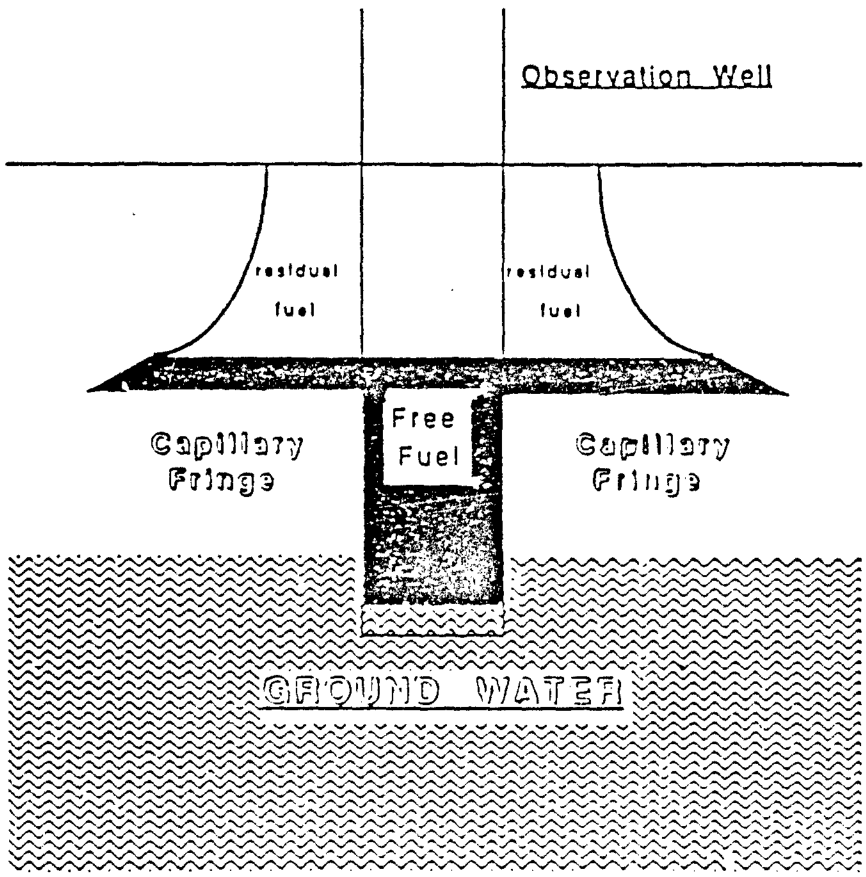
sublethal effects, such as reduced growth in flagfish, were caused by concentrations of 1.5 mg/l in 196 day continuous studies. Accelerated rates of hatching were found in rainbow trout eggs exposed to 0.5 mg/l to 4.0 mg/l and growth was delayed during 112 day exposures at 1.0 mg/l (Fisher et al 1985).

Mutagenic tests conducted on rats exposed to high vapor concentrations of JP-4 were negative, and it was concluded there was no evidence that JP-4 would be carcinogenic (Macewen 1984).

FUEL VOLUME ESTIMATION

Estimation of the total quantity of undissolved JP-4 product in the subsurface environment involves: 1) an estimation of the total volume retained in the unsaturated zone and 2) an estimation of the horizontal and vertical accumulation of the free product in the saturated region directly above the groundwater table. Both of these variables involve immiscible flow processes in the vadose zone. The relationships between the vertical distributions of water, JP-4 and air in porous medium and the corresponding distributions of these fluids in monitoring wells is very complex and is generally thought to be a function of the physical properties of JP-4, water, and air pressures and the pore size distribution of the porous medium. Free product volumes are usually estimated by multiplying the thickness in one or more monitoring wells by the estimated areal extent of contamination and dividing by four (CONCAWE 1979). Some researchers use the CONCAWE equation modifying it with a correction factor taking into account the porosity of the affected soil (Hampton 1989). Unfortunately, it is known that the thickness of JP-4 found in monitoring wells is not indicative of the actual thickness outside of the well. This fact was first observed by Van Dam (1967) when he published a paper on the migration of hydrocarbons in

water bearing stratum. Van Dam reasoned from Darcys Law, that fluid potential and relative permeability were appropriate for describing the flow of multiple fluids in a porous medium. However Darcys Law was only appropriate for the flow of a single fluid in a porous medium. To make Darcys Law suitable to describe multiple fluid flow (i.e. fuel, air and water) Van Dam added a capillary pressure term to the potential equation which led to the creation of a saturation - dependent fluid potential describing variations of capillary pressures in the three phase system. This research provided the fundamental information that led to the discovery that the actual fuel thickness differed from apparent fuel thickness as seen in monitoring wells. Researchers have also confirmed the discrepancy between the "apparent" fuel thickness and the "actual" fuel thickness. It is postulated that the thickness of the fuel in a well is equal to the thickness of the capillary fringe, plus the actual thickness of the fuel outside the well plus the thickness of the water level depression in the well due to the fuel's weight (Figure 3) (Zilliox 1975, Farmer 1983). This theory may have laboratory applications, however field application of this idea is extremely difficult as there is no current method of accurately measuring the appropriate capillary fringe.



FROM: MILLIGAN, 1989

FIGURE 3 PROFILE OF PETROLEUM CONTAMINATED AQUIFER

In 1984, Yaniga identified another problem with the measurement of monitoring well fuel thickness. It involved the dynamic hydrological conditions in aquifers (Yaniga 1984). He found that during periods of recharge when the water table is rising, fuel thickness in observation wells decreased, often to the point of disappearance. Conversely during periods when the water table fell, fuel thickness in wells can increase. This phenomenon, which is influenced by each aquifer's physical characteristics, (particle size, porosity) can obviously result in erroneous volume estimates. The two factors which seem to influence this occurrence are the adsorptive capacity of the site specific geologic materials and gravity. The adsorptive capacity of the site specific geologic material is greatly influenced by the organic and clay content which may bind the fuel both through chemical and physical properties. Product, after a loss to the subsurface, will move downward under the influence of gravity. Resisting the downward movement of the product are the adsorptive forces/affinity of certain geologic materials such as clay and silt to retain/hold on to a portion of the fugitive material. Given sufficient product loss to overcome the adsorptive capacity, in the residence time allowed, the product continues to move downward under the force of gravity until reaching the lower restrictive horizon of the water table.

Many researchers have found the discrepancy between actual and observed fuel thickness problem to be extremely complex due to the three phase distributions under mechanical equilibrium, inability to accurately relate fluid contents to capillary pressures, and fuel density changes. Due to these problems, various study groups have concluded that no simple linear conversion scheme can be employed to relate the thickness of the hydrocarbon in the monitoring well to the hydrocarbon volume in porous media. (Hampton 1988, Milligan 1989, Farr et al. 1990, Lenhard and Parker 1990).

This project compared existing quantitative methods in an attempt to understand these problems and the variables involved so an accurate estimate of the actual thickness of recoverable fuel product can be made. The thickness estimates can be used in a free product volume estimate of the contaminated site if the areal extent of contamination is known.

PREDICTIVE RELATIONSHIPS

From information presented above, it is determined that the accurate determination of free fuel thickness in groundwater through the use of monitoring wells is greatly influenced by site specific geology in the aquifer under study and the capillary fringe phenomena.

This problem has been investigated by several researchers who have attempted to establish a predictive relationship between the "apparent" fuel thickness in monitoring wells and the "actual" fuel thickness in the adjacent aquifer. The first widely used predictive relationship was issued by the oil companies international study group for conservation of clean air and water - Europe (CONCAWE) which presented a rule of thumb technique for estimating actual hydrocarbon product thickness in soils (CONCAWE 1979). CONCAWE stated that because of air, water and fuel capillary pressure relationships, the apparent fuel thickness may be as much as four times the actual thickness and volumes determined from measurements taken in monitoring wells should be adjusted accordingly. The simplified CONCAWE method may have applications with the input of corrected fuel densities. Hampton et al. (1989) found a "modified" CONCAWE equation to correlate very closely with actual product thicknesses which were determined through three separate unique determinations

(bailer test, Hampton probe, infiltration pit) in field study of a gasoline contaminated area (personal communication, April 12, 1990). Other researchers have also developed equations predicting the actual product thickness, (Yaniga & Warburton 1984, Blake & Hall 1984, Schiegg 1984) however for the most part the equations did not predict the actual product thickness when verified under field and laboratory conditions, hence they are not used in field applications. (Hampton 1988).

If equilibrium and somewhat homogeneous conditions are assumed, the relationship between the "apparent" thickness of JP-4 in a monitoring well and the volume of JP-4 in the soil formation can be determined. The condition of static equilibrium is very important (Farr et al. 1990). Together with observed fluid levels in monitoring wells, it permits calculation of the spatial distribution of fuel - water and air - fuel capillary pressures in the porous medium (Corey 1986). Then prescribed functions relating fluid contents and capillary pressures can be translated directly to spatial distributions of fluid content. Finally, vertical integration of the fuel content yields the estimated volume of fuel in the porous medium including the unsaturated zone.

The basic data required to determine the relationship between well bore and soil formation JP-4 are:

a. ρ_w : density of the soil water

b. ρ_o : density of the JP-4

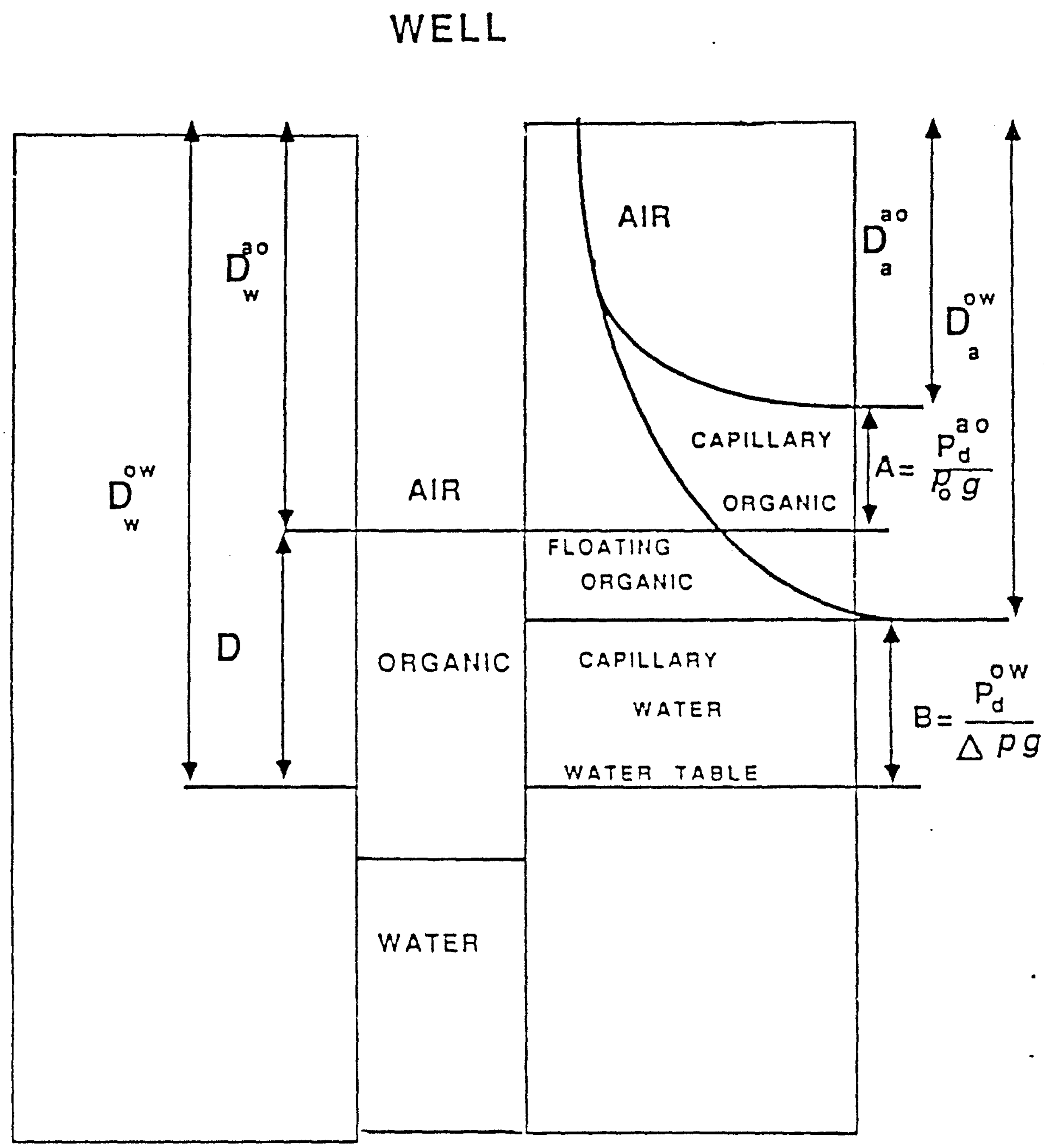
c. ρ_a : density of air (assumed zero)

d. ϕ : porosity

e. $\frac{Pc[S]}{\rho g}$: capillary pressure-saturation curves for an air/organic system and for an organic/water system.

The relevant porous medium properties are incorporated through the functions used to relate fluid contents to capillary pressures (Corey 1986, van Genuchten 1980).

After a petroleum spill, static conditions are assumed, as illustrated in Figure 4. The key to this diagram is the capillary region of the fuel (A) and water (B), which will be determined by finding D_a^{ao} and D_a^{ow} respectively. The depth D_a^{ao} is the depth in the porous medium at which the air - JP-4 capillary pressure is the minimum required for continuous air and organic liquid to exist simultaneously within a representative volume element. Similarly, the depth D_a^{ow} is the depth in the porous medium at which the organic - water capillary pressure is the minimum required for continuous organic liquid and water to exist simultaneously. The values of D_a^{ao} and D_a^{ow} are calculated from hydrostatics (Corey 1986) with knowledge of



FROM: MILLIGAN, 1989

FIGURE 4 NOTATION USED FOR EQUILIBRIUM CONDITIONS

the relevant displacement pressures and the interface levels in an observation well.

The following results are obtained:

$$D_a^{ao} = D_w^{ao} - \frac{P_d^{ao}}{\rho_o \, g} \qquad (1)$$

$$D_a^{ow} = D_w^{ow} - \frac{P_d^{ow}}{(\rho_w - \rho_o) \, g} \qquad (2)$$

where P_d^{ao} = air - organic displacement pressure,

P_d^{ow} = organic - water displacement pressure,

and g = acceleration of gravity.

The volume of organic (V_o) in the soil relates to the capillary pressure curve parameters as defined by the Brooks-Corey relationship (A, B, and λ) and the depths to the organic water interface (D_a^{ow}) and air organic interface (D_a^{ao})
as delineated by the location of the displacement pressures in the Brooks-Corey relationship. (λ = from Brooks-Corey parameters, is an empirical exponent used as index of pore size distribution). It still remains to relate the volume of organic to the measurable depth of organic in the well bore.

The following relationships that are defined in Figure 3 are used to establish the relationship:

$$D + A - B = D_a^{ow} - D_a^{ao} \qquad (3)$$

$$D_w^{ow} - D - A = D_a^{ao} \qquad (4)$$

$$D_w^{ow} - B = D_a^{ow} \qquad (5)$$

$$D_w^{ow} - D = D_w^{ao} \qquad (6)$$

and

$$V_o = \phi\,[D+A-B] + \frac{A\,\phi}{-\lambda+1}\left[\left(\frac{D_w^{ao}}{A}\right)^{-\lambda+1} - 1\right] - \frac{B\phi}{-\lambda+1}\left[\left(\frac{D_w^{ow}}{B}\right)^{-\lambda+1} - 1\right]$$

equation (7)

The value of $\phi\,[D + A - B]$ equals the volume of free petroleum product in the soil formation. Subtracting approximately 80% of this value from V_o leaves the volume of the fuel residual in the soil formation per unit area (typically 20 percent of the saturated free product is residual (AFESC draft report ESL-TR-89-53). For the remainder of this paper, equation (7) is known as the Air Force (AF) equation. For calculated thickness data shown in all tables and figures, equation (7) was used when AF is indicated.

The software package SOILPROP was used in calculating the P_d^{ao} and P_d^{ow} displacement pressures, based on grain size distribution computation of the P_d^{aw} value. (Lenhard & Parker 1990).

The CONCAWE equation modified to reflect the corrected JP-4 fuel density to be used follows: (CONCAWE 1979).

$$\frac{H}{h} \approx \frac{H-a}{h-a} = \frac{P_c^{ow}}{P_c^{oa}} \frac{(\rho o - \rho a)g}{(\rho_w - \rho_o)g} = \frac{P_c^{ow}}{P_c^{oa}} \frac{\rho o}{1-\rho o} \approx 4 \frac{P_c^{ow}}{P_c^{oa}}$$

equation (8)

H = apparent product thickness, measured in well.

h = actual product thickness including product fringe.

a = product-saturated portion of h.

P_c^{ow} = pressure difference (capillary pressure) between water and oil at their interface.

P_c^{oa} = capillary pressure between oil and air.

g = gravitational acceleration.

ρ_w, ρ_o, ρ_a = density of water, oil and air.

For the remainder of this paper, equation (8) is known as Concawe.

The equation developed by Farr et al. for the volume estimation of light nonaqueous phase liquids in porous media evolves from: (Farr 1990).

$$h = \frac{\rho_o}{\rho_w} T \qquad (9)$$

ρ_o = density of organic liquid

ρ_w = density of the water

T = D_w^{ow} - D_w^{ao} is the thickness of the fuel in the well.

It must be noted that the level of neither the fuel nor water in the monitoring well is equal to the water table elevation. The values of D_a^{ao} and D_a^{ow} are calculated according to equations (1) and (2) with knowledge of the relevant displacement pressures and the interface levels in the observation well. The volume of nonresidual fuel in the porous medium is given by:

$$V_o = \phi \{ \int_{D_a^{owa}}^{D_a^{ow}} (1-S_w)\, dz - \int_{D_a^{owa}}^{D_a^{ao}} [1-(S_w + S_o)]\, dz \} \qquad (10)$$

V_o = volume of organic liquid in porous medium per unit area.

ϕ = porosity of medium, S_w = saturation of water,

S_o = saturation of organic liquid

z = vertical coordinate measured positive downward [L]

Evaluation of equation (10) requires that the relationships $S_w(z)$ and $S_o(z)$ be known. Corey (1986) and van Genuchten (1980) presented algebraic equations that express fluid contents as a function of capillary pressure in two fluid systems. Based on the above, the required fluid content relations can be expressed as:

$$S_o + S_w = (1-S_r) \left(\frac{P_c^{ao}}{P_d^{ao}}\right)^{-\lambda} + S_r, \text{ and } S_o + S_w = 1 \qquad (11)$$

$$S_w = (1-S_r) \left(\frac{P_c^{ow}}{P_d^{ow}}\right)^{-\lambda} + S_r \qquad (12)$$

(using the Corey equation)

S_r = residual saturation of water.

λ = Brooks-Corey pore-size distribution index.

Integration of equation (10) using the relationships presented in equations (11) and (12) yields the following equation which will be called the Farr equation:

$$V_o = \phi \frac{(1-S_r)D}{1-\lambda} \{\lambda + (1-\lambda)(T/D) - (T/D)^{1-\lambda}\} \quad \neq 1 \qquad (13a)$$

and

$$V_o = \phi\ (1-S_r)\ [1-D(1 + \ln T)], \quad \lambda = 1. \qquad (13b)$$

where

$$D = \frac{P_d^{ow}}{g} - \frac{P_d^{ao}}{\rho_o\ g} \quad \text{and } T = D_w^{ow} - D_w^{ao} \geq Pd^{ow}/\Delta\rho\ g.$$

λ = Brooks Corey (BC) pore size distribution index.

T = Thickness of fuel layer in the monitoring well.

S_r = residual saturation of water.

All other notations used are the same as in equation (7). For calculated thickness data indicated Farr in all tables and figures, equation (13a) was used.

Table 1

SUMMARY OF THE DIFFERENCES BETWEEN CONCAWE, FARR, AF EQUATIONS.

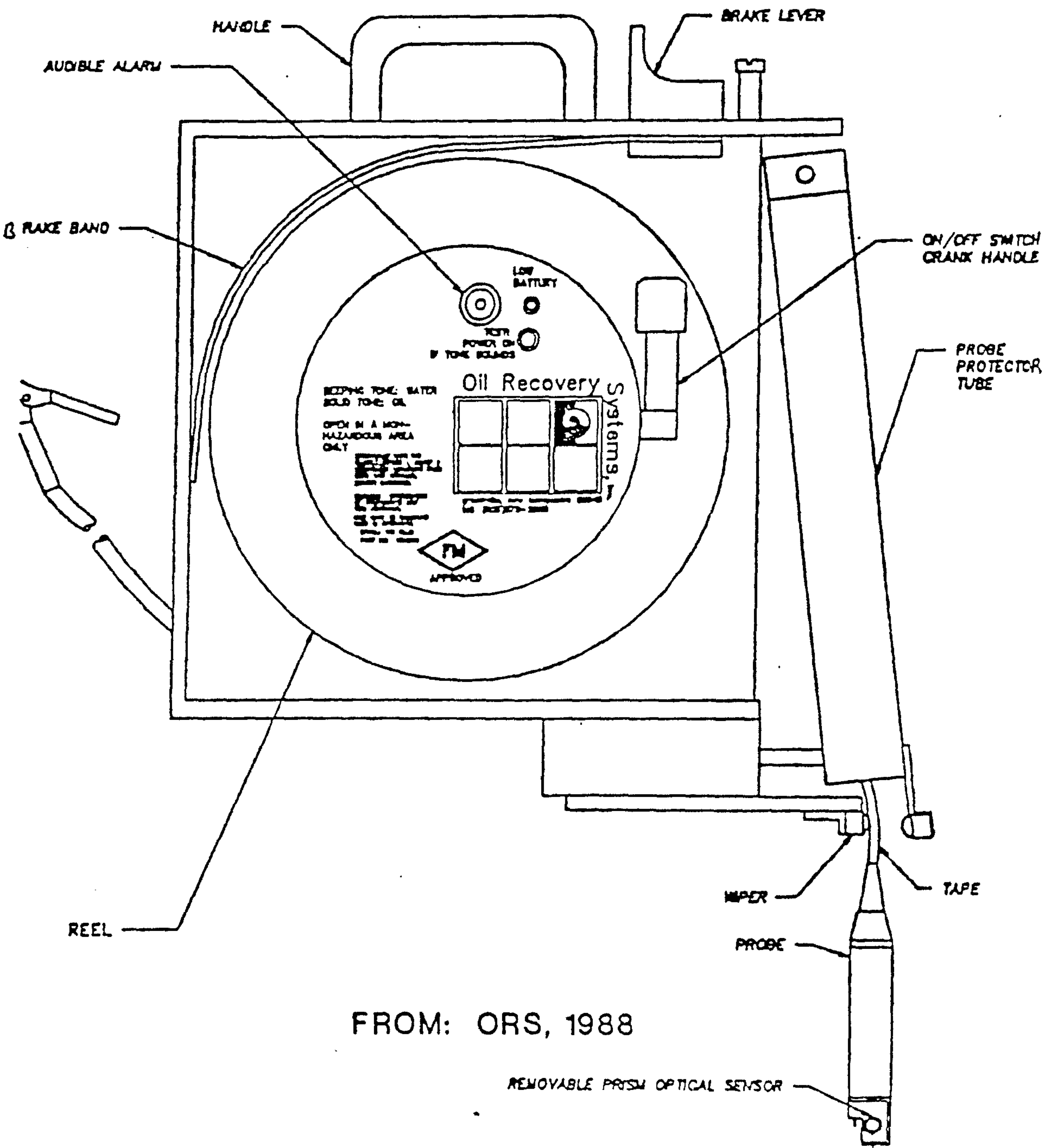
Is calculated thickness a function of:	Concawe	AF	Farr
Oil density?	Yes	No	No
Porosity (ϕ)?	No	Yes	Yes
Oil-water surface tension?	No	Yes	Yes *
Particle size distributions? (Brooks-Corey empirical exponent)	No	Yes	Yes
Residual Saturation (S_r)?	No	No	Yes
Depth of product below the ground surface?	No	Yes	No
Observed Thickness?	Yes	Yes	Yes

* = Only above 8 dynes/cm.

METHODOLOGY

Air Force or contractor personnel at the following Air Force Bases Bases (AFBs) conducted periodic measurements of fuel thickness and depth to groundwater: Homestead AFB FL, Shaw AFB SC, Langley AFB VA, Edwards AFB CA, Williams AFB AZ, and Columbus AFB MS. At some locations the measurements were done weekly or monthly; at other locations the measurements were done on an intermittent basis. At most AFBs the monitoring period was March 1989 through August 1990. The appropriate appendix associated with each AFB contains the raw data for each date of monitoring, including the observed fuel thickness level and depth to groundwater reading.

The JP-4 thickness and depth to groundwater levels were measured at all locations using an Oil Recovery System (ORS) Environmental Equipment Interface Probe, see figure 5, for an illustration of the probe. (ORS, Greenville NH). The probe contains two different sensor units, one for detecting the liquid-air interface, and one for distinguishing between water and hydrocarbon. The liquid sensor is an optical prism located on the end of the probe. The sensor detects liquid by reacting to the differences in the indices of refraction of air and liquids. An infrared light source is internally reflected to an infrared detector by a prism on the face of the sensor. When the prism becomes immersed in



FROM: ORS, 1988

FIGURE 5 ORS INTERFACE PROBE

liquid, the light beam is refracted away from the detector. To determine if the liquid is conductive (water) or nonconductive (hydrocarbon), a small electrical current is passed between two electrodes on the sensor. Current flow will occur only in conductive fluids such as water. The interface Probe is capable of measuring oil films less than 1/100 of a foot in thickness (reference ORS Interface Probe Instruction Manual).

After taking the readings of the fuel thickness and depth to water, personnel recorded the measurements on data sheets provided and sent the readings to the author.
After receiving the measurement data from the bases, the information was converted to metric units for use in the three relevant equations. The observed low, average and high JP-4 thickness readings were selected for input into the three relevant equations. The average value was obtained by taking the sum of all the thickness readings and dividing by the number of observations.

Base personnel also furnished to the author the well logs and any soil particle size distributions conducted at or near the JP-4 contaminated site. The well logs were interpreted utilizing the American Society of Testing Materials (ASTM) Method D422 (MD422). The soil classifications were assigned diameters employing tables

found in this method.

TABLE 2. ASTM CATEGORIES OF PARTICLE SIZE VERSUS CLASSIFICATION FACTOR

	diameter (mm)	Sieve Size
Fines (clay and silt)	0.001 to 0.08	#200
Fine sand	0.08 to 0.5	#40,#60, #100
Medium sand	0.5 to 2	#10,#20
Coarse sand	2 to 5	#4
Fine gravel	5 to 17.5	3/8 to 1 inch
Cobbles	17.5 to > 100	> 1 inch

A potential source of error exists when making the determination of assigning fractions of the soil in question into each ASTM class. This procedure was done by taking the well logs (see appropriate Appendix for examples) and interpreting the well driller or geologist's visual classification of the soil and assigning the relevant particle size. This procedure involves some subjectivity on the part of the author due to the incompleteness or vagueness of many geologist's descriptions of well core samples.

In some cases the geologist used the Unified Soil Classification (USC) scheme (Figure 6) when assigning soil properties from the well cores. This procedure was only used in approximately 8 of the 21 wells included in this

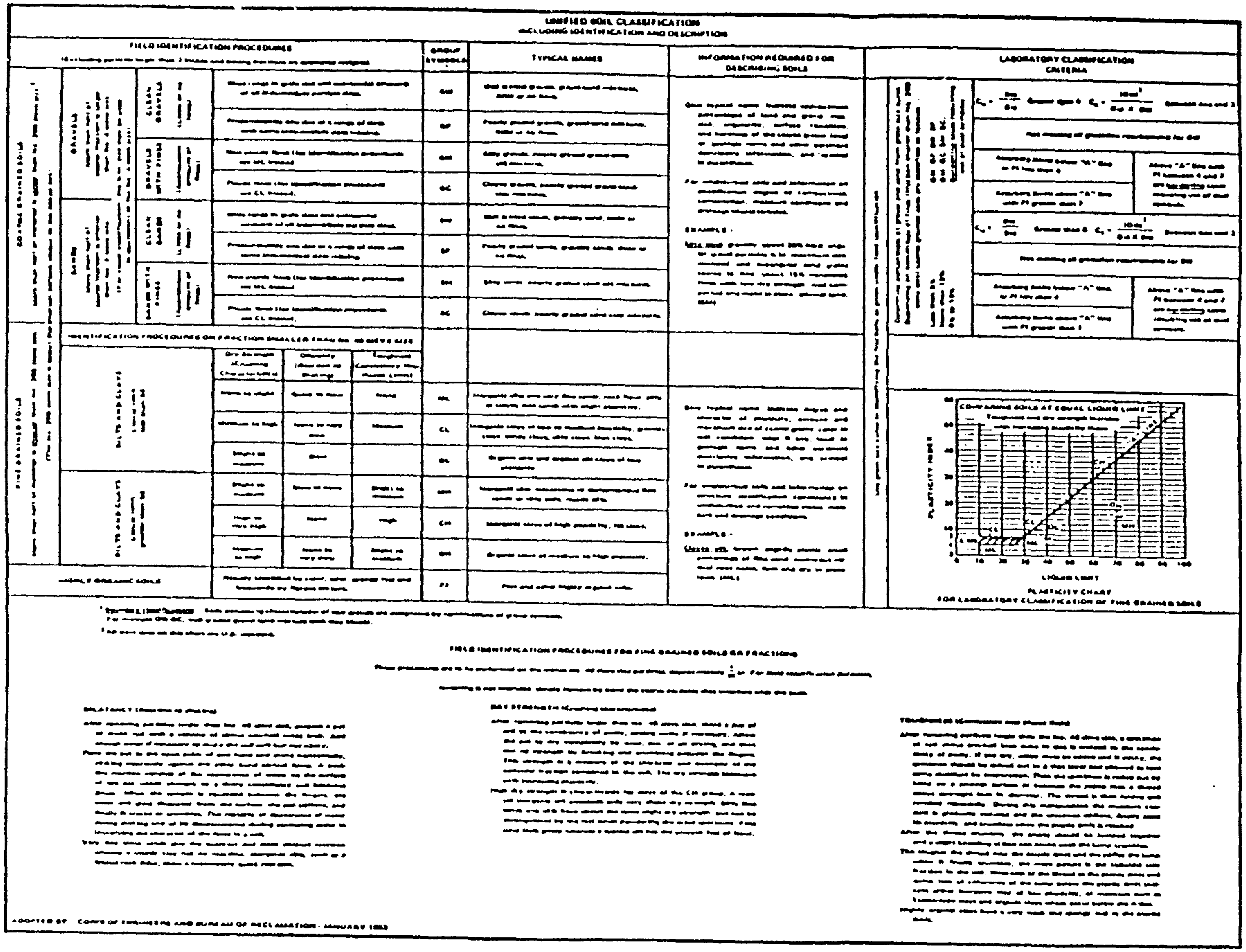


FIGURE 6 UNIFIED SOIL CLASSIFICATION CHART FROM: HAMPTON, 1989

project. When the well log included the USC classification system it made assigning the ASTM particle sizes much easier and provided continuity in the process. However determination of percentages of each fraction still had to be made from the well logs provided.

An additional source of error introduced into the process was the fact that many well logs were unavailable for assessment. In those instances well logs from nearby wells were used and the relevant soil properties were assigned as needed. If particle size distributions (PSDs) were provided the above procedures were not necessary.

After the particle size distributions (PSDs) of each well were determined from the PSD curve or the well log, the information was input into SOILPROP, (Environmental Systems & Technologies, Inc., Blacksburg, VA) an interactive program for estimating soil hydraulic properties from particle size distribution data.

SOILPROP is based on the premise that the soil-water retention functions, (theta _ h θ_h), reflects an underlying pore size distribution which can be deduced from the particle size distribution. SOILPROP converts PSD data to $_h$ data using the algorithm of Arya and Paris (AP) as modified by Mishra et al. (1988). Briefly, the AP method

involves dividing the particle size cumulative distribution function (CDF) into a number of fractions, assigning a pore volume and a volumetric water content to each fraction, and then computing a representative pore radius and a corresponding capillary pressure head. This results in a complete θ_h functional relationship.

The specific soil properties of interest from SOILPROP are the parameters in the Brooks-Corey (BC) model (Corey, 1986) for water retention relations. The BC method of retention is used in both the AF and Farr equations.

An example of an output from SOILPROP is shown on the following page. The Brooks-Corey (BC) method was chosen as the method for determining retention parameters in both the Farr and AF equations. This was done to insure a valid method of comparison could be made between the two equations. The AF equation only uses the BC method for retention parameters (Milligan, 1989), whereas the BC option is one of two when using the Farr equation. The primary numbers used from the SOILPROP outputs were the air-water capillary head (Pd^{aw} or h_d, lambda, and S_r (residual saturation, S_r). Lambda and S_r are used directly in the AF or Farr equations. The Pd^{aw} number generated was used to determine Pd^{aw} and Pd^{ow} used in the AF and Farr equations

```
*********************************************
*               S O I L P R O P             *
*A program to estimate soil hydraulic properties*
*     from particle size distribution data   *
*                                           *
*      COPYRIGHT  1990  Version 2.1         *
* Environmental Systems and Technologies, Inc. *
* P.O. Box 10457, Virginia 24062-0457       *
*             (703) 552-0685                *
*********************************************


*********************************************
*             Shaw AB SC All wells          *
*********************************************

-------- PARTICLE SIZE DISTRIBUTION DATA --------

         % fines (clay/silt) =>  3.00
         % fine sand         =>  3.00
         % medium sand       => 90.00
         % coarse sand       =>  4.00
         % fine gravel       =>   .00

         R^2 for log-normal fit => .7169


         theta_s (cc/cc)     =>   .40
         % error in theta_s  =>  5.00
         bulk density (g/cc) =>  1.59
         % error in bulk den =>   .00

         R^2 for V_G model  fit => .9821

    Irreducible water saturation / water content
     set equal to theta at which capillary head
        equals user-specified critical value

------ VAN GENUCHTEN RETENTION PARAMETERS -------

                       Estimated         Standard
                         value           deviation

    alpha (1/cm)          .126            .347E-01
    n                     2.85            .354
    theta_r(cc/cc)        .169E-01        .203E-02
    K_s (cm/d)            .388E+05        .456E+09

--------- PARAMETER CORRELATION MATRIX ----------

                  alpha          n
    alpha       .100E+01
      n         .440E+00     .100E+01


    Irreducible water saturation / water content
     set equal to theta at which capillary head
        equals user-specified critical value

------ BROOKS-COREY  RETENTION PARAMETERS -------

                       Estimated         Standard
                         value           deviation

    h_d (cm)              5.22            1.36
    lambda                1.22            .190
    theta_r(cc/cc)        .169E-01        .203E-02
    K_s (cm/d)            .388E+05        .456E+09

--------- PARAMETER CORRELATION MATRIX ----------

                   h_d         lambda
      h_d       .100E+01
    lambda     -.343E+00     .100E+01
```

TABLE 3 EXAMPLE OF SOILPROP OUTPUT

based on the following expression:

$$\frac{P_d^{aw}}{\sigma_{aw}} = \frac{P_d^{ow}}{\sigma_{ow}} = \frac{P_d^{ao}}{\sigma_{ao}} \qquad (14)$$

where σ_{ij} = surface tension between fluids i and j, (Farr, 1990).

An example of a calculated JP-4 thickness in soil from observed thickness in a monitoring well follows:

<u>Well PZ608 SHAW AFB SC</u>

Observed Average JP-4 thickness = 54.2 cm

<u>Concawe:</u> equation (8), density = 0.77 g/cm^3

$$\frac{H}{h} \approx \frac{H-a}{h-a} = \frac{P_c^{ow}}{P_c^{oa}} \frac{(\rho o - \rho a)\, g}{(\rho_w - \rho_o)\, g} = \frac{P_c^{ow}}{P_c^{oa}} \frac{\rho o}{1-\rho_o} \approx 3.34\, \frac{P_c^{ow}}{P_c^{oa}}$$

Simply use the 3.34 Concawe factor:

$$\frac{54.2\text{ cm}}{3.34} = 16.2\text{ cm}$$

Farr. (equation 13a)

Note: use porosity (ϕ) = 0.4, σ_{ow} = 15 dynes/cm for the Farr and AF equations.

$$V_o = \phi \frac{(1-S_r)\ D}{1-\lambda} \{ \lambda + (1-\lambda)(T/D) - (T/D)^{1-\lambda} \} \quad \lambda \neq 1$$

$$\text{where } D = \frac{P_d^{ow}}{\Delta \rho\, g} - \frac{P_d^{ao}}{\rho\, g} = \frac{h_d\ (\rho w)}{\sigma_{aw}} \left[\frac{\sigma_{ow}}{(\rho_w - \rho_o)} - \frac{\sigma_{ao}}{\rho_o} \right]$$

$$\text{and } T = D_w^{ow} - D_w^{ao} \geq P_d^{ow}/\Delta \rho\, g.$$

$$= \text{(observed thickness of JP-4 in the well)}$$

$$D = \frac{cm \ \frac{g}{cm^3}}{\frac{g}{cm^2\ sec^2}} \left[\frac{\frac{g}{cm^2\ sec^2}}{\frac{g}{cm^3} - \frac{g}{cm^3}} - \frac{\frac{g}{cm^2\ sec^2}}{\frac{g}{cm^3}} \right]$$

$$D = \frac{\frac{g}{cm^2}}{\frac{g}{cm^2\ sec^2}} \left[\frac{\frac{g}{cm^2\ sec^2}}{\frac{g}{cm^3}} \right]$$

$$D = cm$$

$$D = \frac{(5.22\ \ h_d)\ (1)}{59}$$ from SOILPROP
from Milligan 1989

$$= 0.088 \left[\frac{15}{.23} - \frac{27.3}{.77} \right]$$ from Milligan 1989

$$= 0.088\ [29.76]$$

D = 2.62 cm $\qquad S_r$ = 0.017, lambda = 1.22 from SOILPROP

$$V_o = \frac{0.4\ (.983)\ 2.62}{-0.22} \left[1.22 + (-.22)\left(\frac{54.2}{2.62}\right) - \left(\frac{54.2}{2.62}\right)^{-.22}\right]$$

$$= -4.68 \quad [-3.84]$$

V_o = $\underline{17.9 \text{ cm}}$ = average thickness of JP-4 on the aquifer

Air Force (AF) method: Equation (7)

$$V_o = \phi\,[D+A-B] + \frac{A\,\phi}{-\lambda+1}\left[\left(\frac{Dw^{ao}}{A}\right)^{-\lambda+1} - 1\right] - \frac{B\,\phi}{-\lambda+1}\left[\left(\frac{Dw^{ow}}{B}\right)^{-\lambda+1} - 1\right]$$

$$A = \frac{Pd^{ao}}{\rho_o} \qquad B = \frac{Pd^{ow}}{(\rho_w - \rho_o)}$$

From equation 14, $\frac{P_d^{ao}}{\sigma_{ao}} = \frac{2.4}{27.3} = 0.088;\quad A = \frac{2.4}{.77} = 3.11$ cm

and $\frac{P_d^{ow}}{\sigma_{ow}} = \frac{1.32}{15} = 0.088;\quad B = \frac{1.32}{.23} = 5.74$ cm

$$V_o = 0.4\,(54.2 + 3.11 - 5.74) + \frac{3.11\,(0.4)}{-0.22}\left[\left(\frac{1366}{3.11}\right)^{-.22} - 1\right] - \frac{5.74\,(0.4)}{-.22}\left[\left(\frac{1420}{5.74}\right)^{-.22} - 1\right]$$

$$= 20.68 + 4.17 - 7.33$$

$V_o = 17.5$ cm

Summary.

Observed thickness = 54.2 cm

Concawe = 16.2 cm Concawe factor = 3.34

Farr = 17.9 cm "Concawe factor" = 3.02

AF = 17.5 cm "Concawe factor" = 3.09

Previously published "Concawe factors" for JP-4 ranged from 3.2 to 4. (Hampton, 1989).

RESULTS AND DISCUSSION

This section contains information concerning the JP-4 contaminated site history, geology, observed JP-4 levels, calculated JP-4 thickness, effects of porosity and surface tension on the estimated JP-4 thickness, and site-specific conclusions about the calculated answers. When the term "baseline condition" is used in this section, it refers to a calculation using the Farr or Air Force (AF) equation using a porosity of 0.4 and a oil-water surface tension (σ_{ow}) of 15 dynes/cm. These parameters were chosen as standards for equation comparison.

SHAW AFB SC

SITE HISTORY

Base personnel discovered the presence of a floating layer of JP-4 at this location in July, 1987, during a Phase II Installation Restoration Program (IRP) investigation. The JP-4 contaminated area of Shaw AFB is located near the Petroleum, Oil, and Lubricant (POL) JP-4 storage area. The area of floating product contamination is thought to be approximately 7 acres, approximately 47 feet below grade. The floating product is monitored through five monitoring wells, PZ608, PSPZ2, PZ606, PZ601A and MW505. See appendix 1, SHAW, for the observed values of JP-4 thicknesses and water table elevation levels. The monitoring wells are all located within a 1000 foot circumference area near the POL area. No remediation efforts or artificial changes were introduced in the area of contamination over the seventeen months the JP-4 levels were monitored, except for minor pump tests of the wells and a short duration pilot field study of a free product recovery system. The Air Force IRP contractor estimated 300,000 to 500,000 gallons of JP-4 to be present at this site (AF 1988 SHAW AFB IRP report).

GEOLOGY

The unsaturated or vadose zone in this area is characterized as sandy clay grading to clayey sand (Unified Soil Classifications (USC) of CL, SP, SC, see SHAW Appendix). The saturated zone is described as coarse sand, grading to medium and coarse silty sand with trace gravel (USC SW, GP, SP). Only three of the five well logs were available for review and assessment, see SHAW Appendix. In addition, only one particle size distribution (PSD) was available for SOILPROP input, and it was taken at the 52-53 foot level, which is slightly below the average water table level.

Through assessment of the PSD data and review of the well logs the input into SOILPROP was: 3% fines, 3% fine sand, 90% medium sand, and 4% coarse sand for the zone of interest, i.e. the floating JP-4 layer and water interface.

OBSERVED JP-4 LEVELS

The variability of the JP-4 levels found over the seventeen months of monitoring in the five monitoring wells at this location was large, without corresponding changes in the water table elevation. The SHAW appendix contains the results of the five wells observed fuel and water levels. The smallest thickness of JP-4 found in the area was 11.6 cm (19 May 89),

and the highest level recorded was 76.2 cm (20 April 89), which is six times the lowest level. The average observed JP-4 level (data from five wells) in the area of contamination was 47 cm over the seventeen month period . The difference in the average levels of JP-4 found between the five wells was only 23.1 cm (from low to high), which indicates a system in relatively good equilibrium between fuel and water. The variation of fuel levels in each well was large as indicated in the table below:

TABLE 4. DIFFERENCES IN OBSERVED FUEL THICKNESS - SHAW AFB

Well	High (cm)	Low (cm)	Difference (cm)
PZ608	76.2	23.5	52.7
PSPZ2	58.8	42.7	16.1
PZ606	55.2	24.1	31.1
PZ601A	57.3	11.6	45.7
MW505	73.7	42.7	31.0

CALCULATED (ESTIMATED) JP-4 THICKNESS

Using the PSD data and well log inputs, SOILPROP generated an air-water capillary (Pd^{aw}) of 5.22 cm at a porosity of 0.4. The additional porosities shown on the next page were input to observe the changing Pd^{aw} fringe:

TABLE 5. POROSITY, SATURATION, AND Pd^{aw} VALUES, SHAW AFB

Porosity	Pd^{aw}	Sr
0.25	7.38	0.0114
0.3	6.5	0.0133
0.4	5.22	0.0169
0.45	4.71	0.0186

S_r = residual saturation of water, used in the Farr equation.

See tables 6-9 for the values of calculated JP-4 levels, using the three stated equations. Figures 7-33 illustrate the table values and indicate the effects of changing porosity and oil-water surface tension (σ_{ow}). Figure 7 illustrates the baseline calculated thickness values for all the Shaw wells. As shown, the trend of greater calculated volume of fuel with increasing porosity is apparent, as is the trend of increased calculated fuel volume with lower surface tension of the fuel-water interface.

The results of the Concawe equation show a linear relationship between the observed and calculated fuel levels. The 3.34 Concawe factor explains this relationship, also see the example Concawe problem in the methodology section. Referring to our baseline data, well PZ608 shows a small range of calculated values at the 54 cm level between all three

equations (range of only 1.7 cm), but at the 76 cm level, a spread of 3.7 cm is seen from high to low, again with the Concawe value at the low end. This trend would be expected to continue with increased fuel levels in this soil type.

In this geologic environment there is good agreement in answers up to 60 cm, after this the spread of answers between the three equations with increased fuel depth may be explained by the fact that Concawe is strictly linear in shape (3.34 factor) over all thicknesses. The Farr and AF equations take into account several variable factors, including porosity, and importantly specific retention. The Concawe answer may be interpreted as having all of the computed volume available for recovery, whereas the AF and Farr answers, in this soil type, reveal values that are slightly above the Concawe answer, due to tailoring of the PSD data to specific capillary fringe zones.

Correction factors ranging from 15-30% are still usually applied to the AF and Farr equation answers, realizing that the entire computed volume may not be recoverable as free product.

SITE CONCLUSIONS

GEOLOGY

For the AF and Farr equations, the calculated thickness of JP-4 fuel present as indicated are highly dependent on correct geologic information being furnished. This factor is not important however when using the Concawe equation. The Shaw calculated answers should be classified as being moderately reliable as one PSD was available for SOILPROP input, however only three of five well logs were available. One can only speculate on the exact soil conditions in the remaining two wells, however, over the small zone of contamination, geologic conditions should not change appreciably.

POROSITY

The importance of having the correct porosity available is paramount as the average concentration of JP-4 calculated at this site differs 9-10 cm over a porosity range of 0.25 to 0.45. The porosity factor within both the AF and Farr equations is highly important, in that it is a multiplicative factor in the equations.

MEASUREMENTS OVER TIME

Taking multiple fuel level measurements of any floating layer is of the utmost importance. Due to the wide variations observed from low to high levels seen in this JP-4 field, the calculated JP-4 levels ranged from 6.0 to 26.2 cm (porosity 0.4). Relying on one or two measurements to calculate the thickness of JP-4 present can as shown in this case lead to volume estimations off by a factor of over three (AF and Farr) and up to five (Concawe).

SURFACE TENSION

The variability of calculated volumes (using Farr and AF) is also affected by the oil-water interfacial tension (σ_{ow}) parameter. At all porosities, the average fuel level can differ six to nine cm as the σ_{ow} varied from 5 to 20 dynes/cm. Relying on a single observation (measured thickness) and not knowing either the porosity or surface tension, using the Farr and AF equations can lead to widely varying answers, zero cm fuel volume (oil-water interface of 20 dynes/cm, porosity of 0.25) to 36.1 cm (oil-water interface of 5 dynes/cm at a porosity of 0.45).

It is recommended that the AF and Farr equations not be used if porosity and oil-water interfacial tensions are unknowns.

The Concawe equation would be the best estimator of the fuel volume present if little or nothing is known about the geology or physical conditions of the fuel.

Figure 7. Shaw AFB SC All Wells Observed vs Calculated Thickness

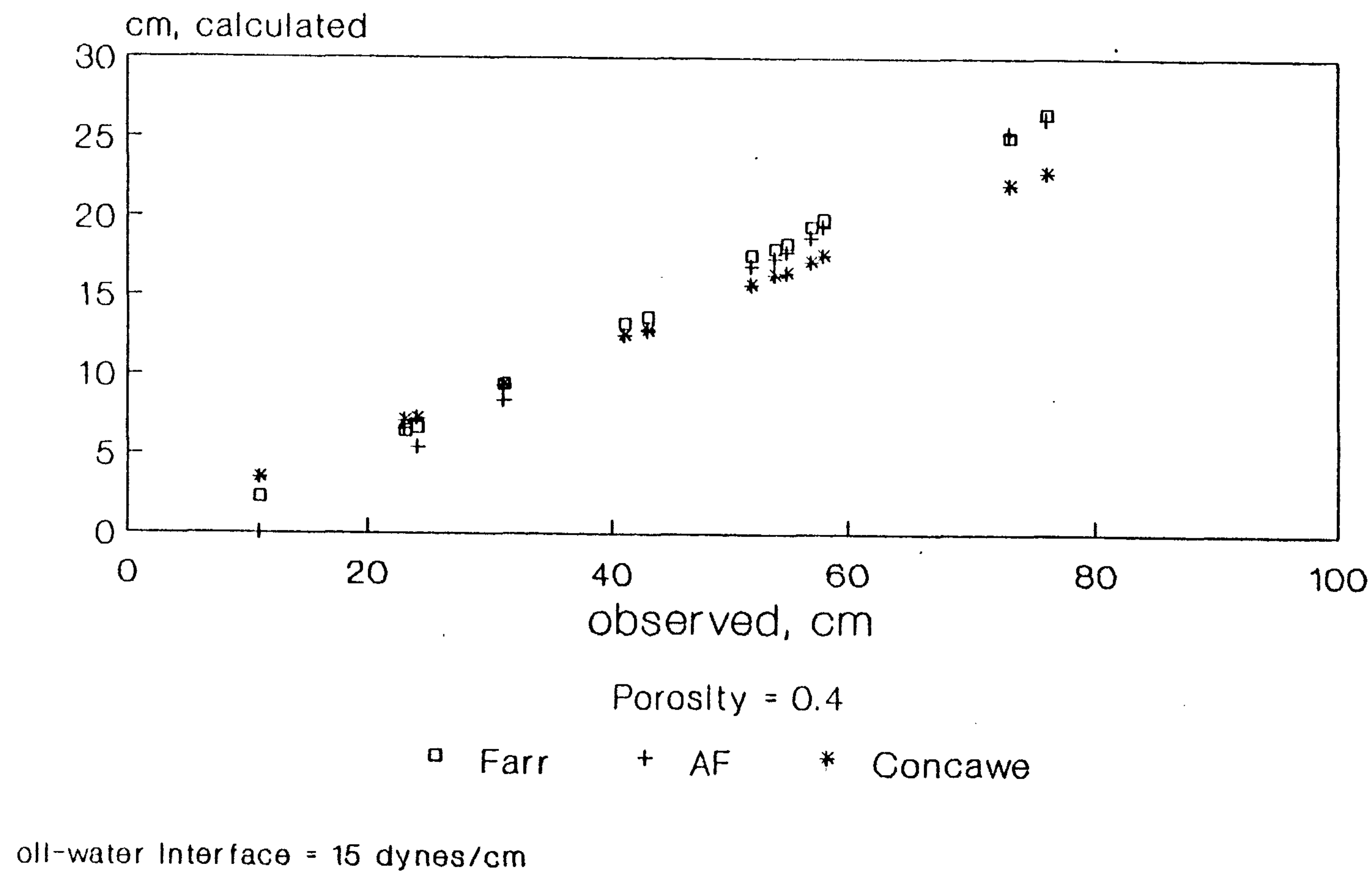


TABLE 6. OBSERVED VS CALCULATED THICKNESS, WELLS PZ606 & PZ601A

SHAW AFB SC Well PZ606	Fuel Thickness CM Observed Low = 42.7 Calculated Value	Fuel Thickness CM Observed Avg = 54.7 Calculated Value	Fuel Thickness CM Observed High = 73.7 Calculated Value
Porosity = 0.4			
Farr at 15 dynes/cm	6.6	13.2	18.3
AF at 15	5.4	12.5	17.8
Concawe	7.2	12.5	16.5
Well PZ601A	Observed Low = 11.6	Observed Avg = 31.6	Observed High = 57.3
Porosity = 0.4			
Farr at 15 dynes/cm	2.2	9.4	19.3
AF at 15	-1.0	8.4	18.7
Concawe	3.5	9.5	17.2

Figure 8. Shaw AFB SC Well PZ601A
Observed vs Calculated Thickness

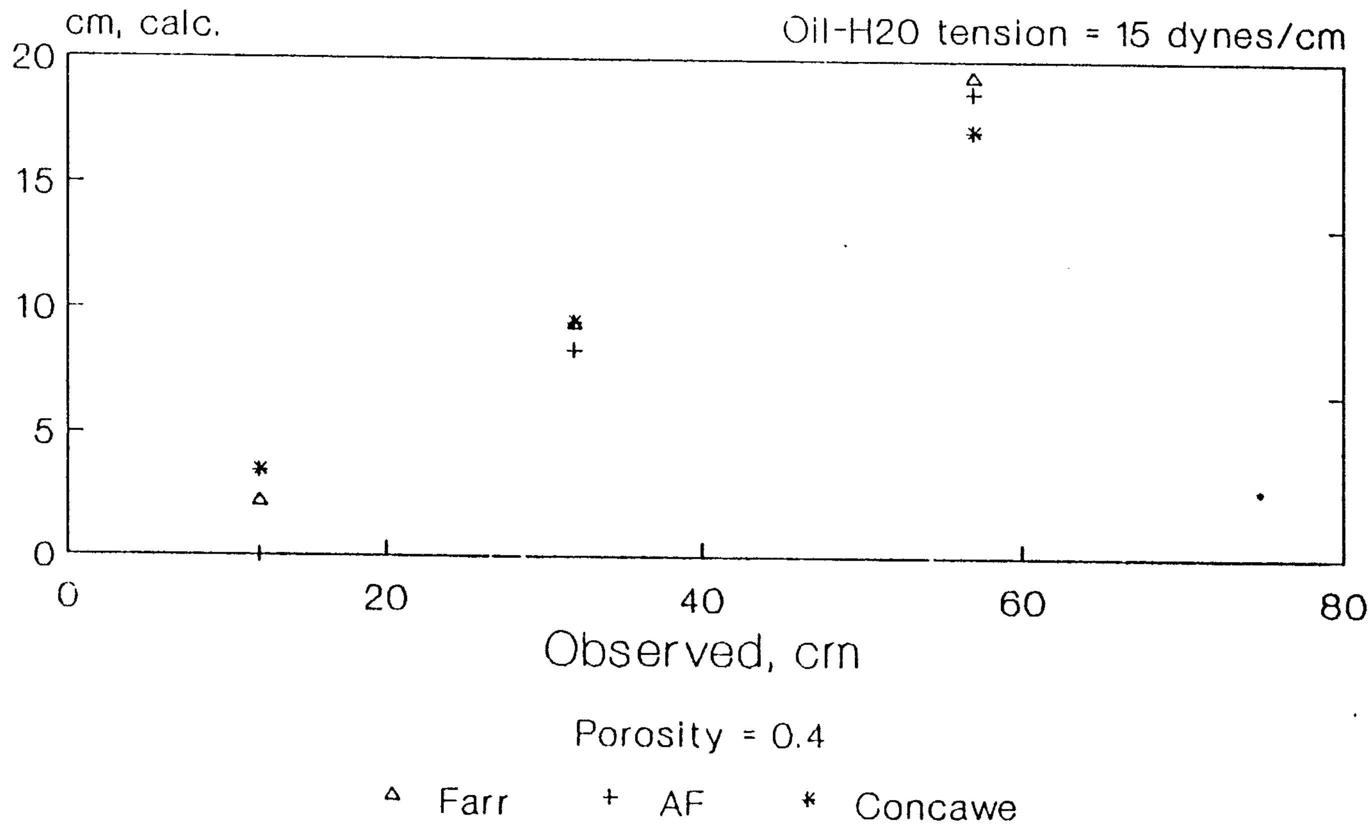


Figure 9. Shaw AFB SC Well PZ606 Observed vs Calculated Thickness

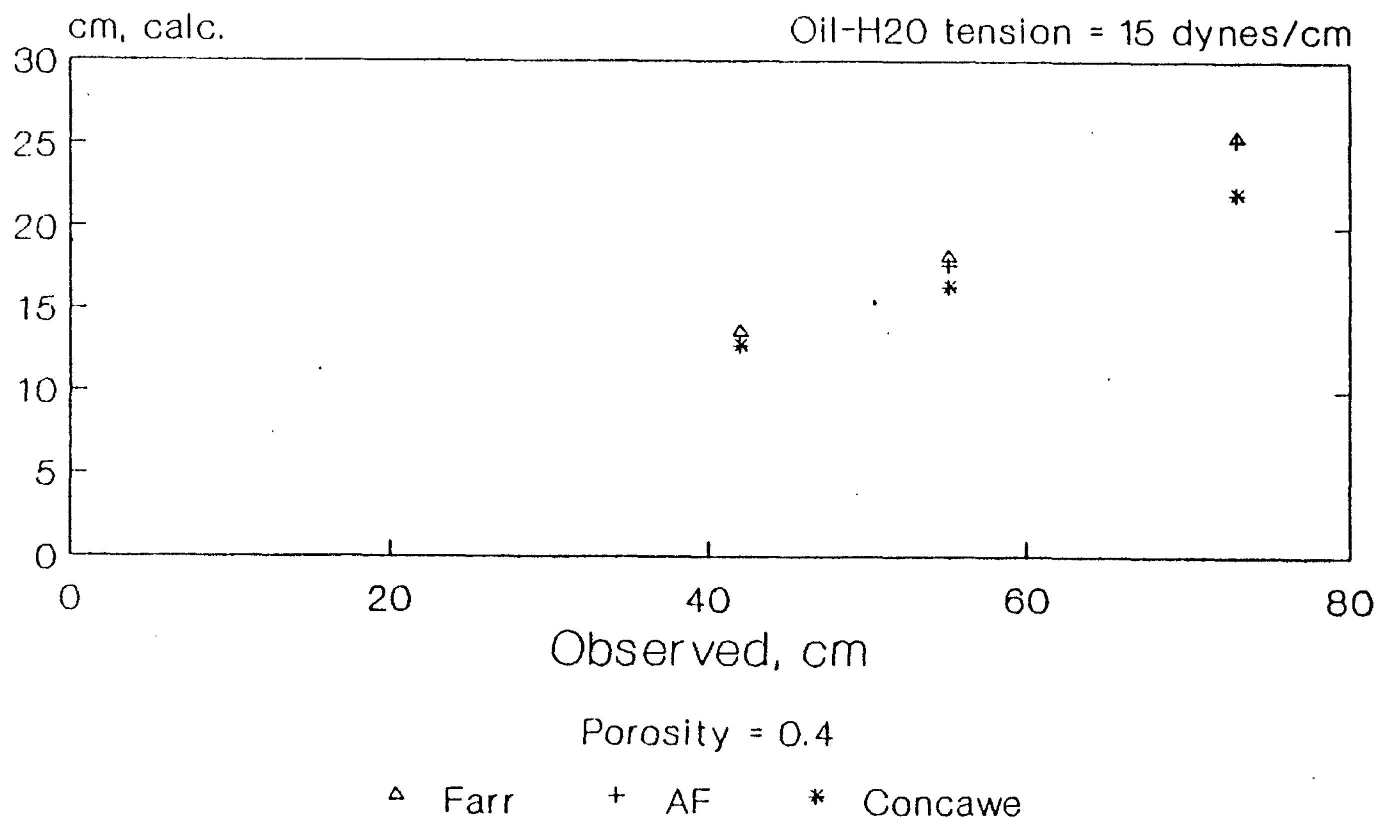


TABLE 7. OBSERVED VS CALCULATED FUEL THICKNESS, WELL MW505

SHAW AFB SC Well MW 505	Fuel Thickness CM Observed low = 24.1 Calculated Value	Fuel Thickness CM Observed Avg = 41.8 Calculated Value	Fuel Thickness CM Observed High = 55.2 Calculated Value
Porosity = 0.25			
Farr at 20 dynes/cm	2.5	6.3	9.3
Farr at 15	3.6	7.6	10.8
Farr at 10	5.1	9.4	12.7
AF at 20	-.1	4.3	7.7
AF at 15	2.4	6.8	10.2
AF at 10	5.0	9.4	12.8
AF at 5	7.6	12.0	15.4
CONCAWE	7.2	12.5	16.5
Porosity = 0.3			
Farr at 20	3.3	7.9	11.6
Farr at 15	4.6	9.5	3.3
Farr at 10	6.2	11.3	15.3
AF at 20	.6	6.0	10.0
AF at 15	3.3	8.6	12.7
AF at 10	6.1	11.4	15.4
AF at 5	8.8	14.1	18.2
Porosity = 0.4			
Farr at 20	5.1	11.5	16.4
Farr at 15	6.6	13.2	18.4
Farr at 10	8.5	15.4	20.6
AF at 20	2.5	9.5	14.9
AF at 15	5.4	12.5	17.8
AF at 10	8.5	15.5	21.0
AF at 5	12.0	19.1	24.5
Porosity = 0.45			
Farr at 20	6.1	13.2	18.9
Farr at 15	7.7	15.1	20.9
Farr at 10	9.6	17.4	23.2
AF at 20	3.4	11.4	17.4
AF at 15	6.5	14.5	20.5
AF at 10	9.6	17.6	23.6
AF at 5	12.7	20.7	26.7

Figure 10. Shaw AFB SC Well MW 505
Observed vs Calculated Thickness

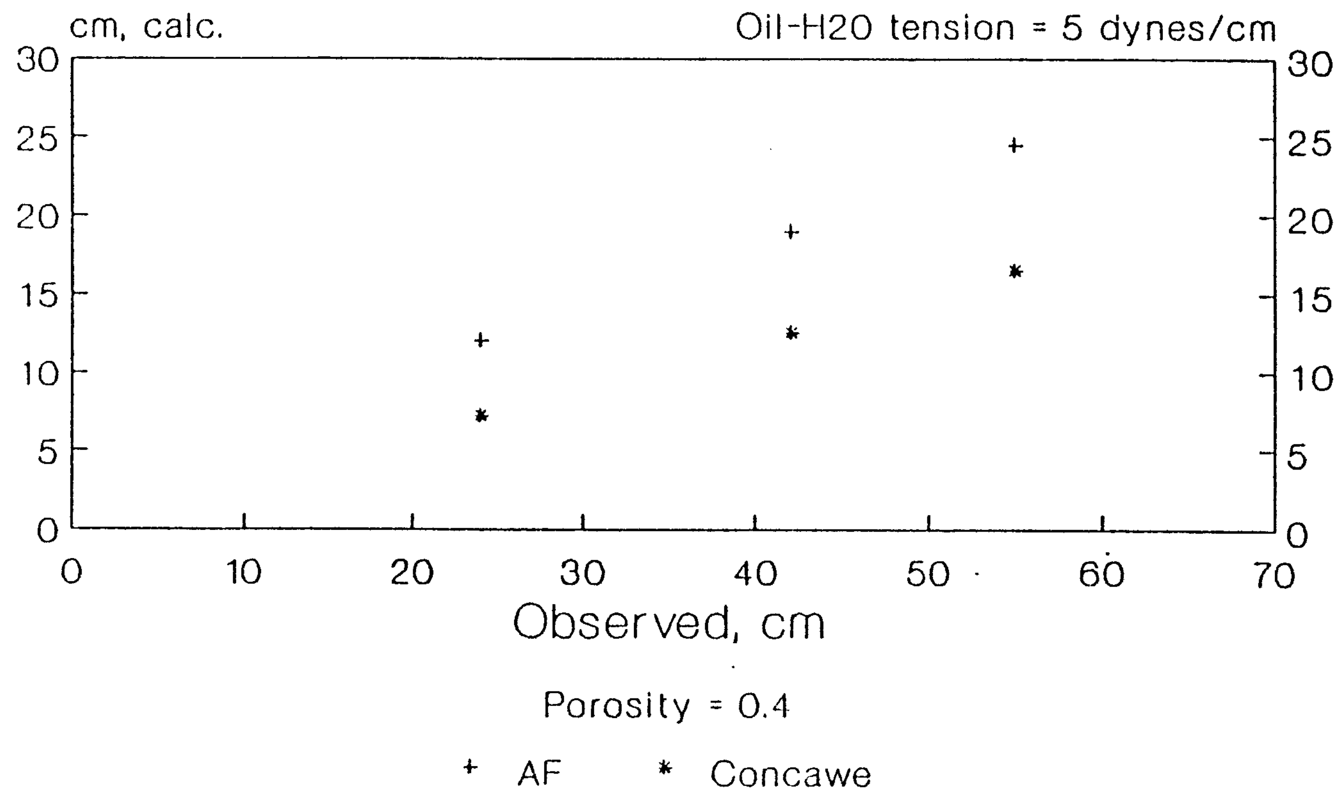


Figure 11. Shaw AFB SC Well MW 505
Observed vs Calculated Thickness

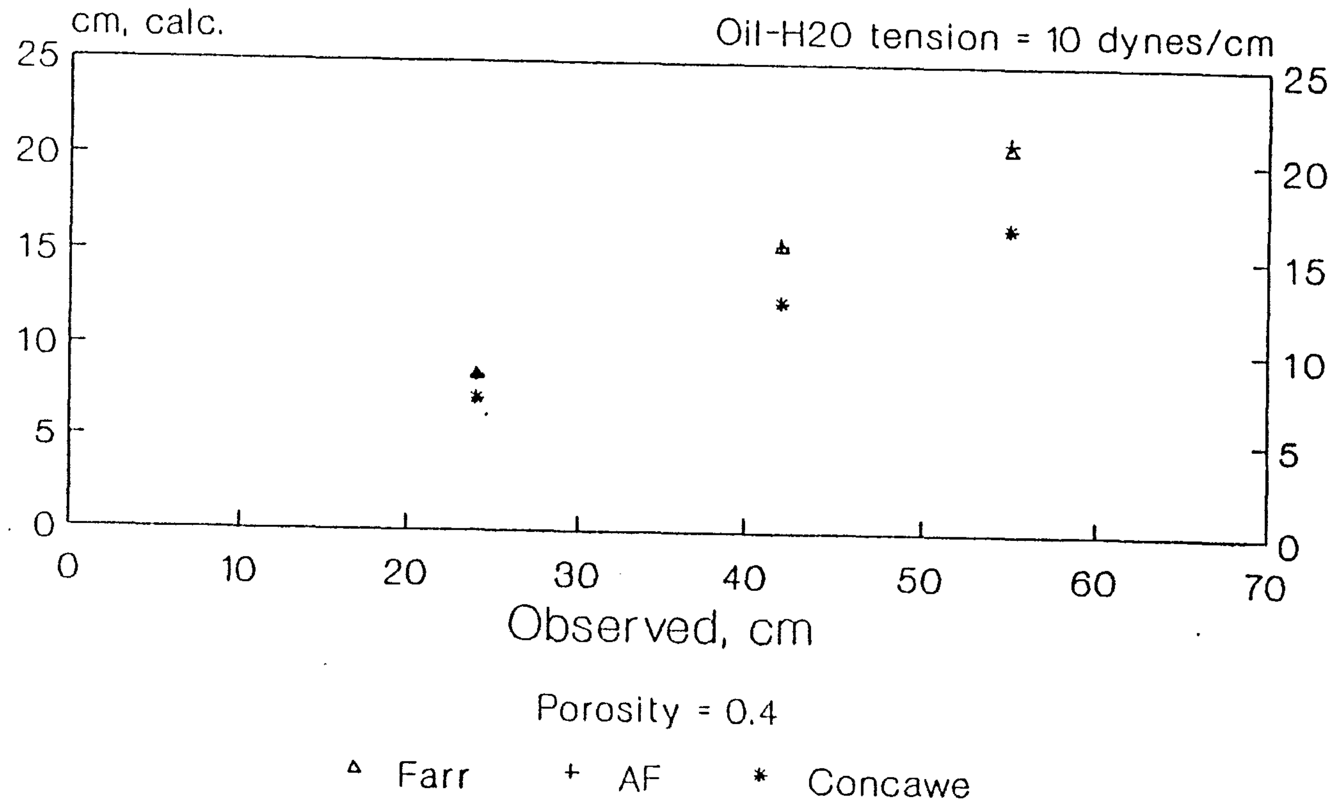


Figure 12. Shaw AFB SC Well MW 505
Observed vs Calculated Thickness

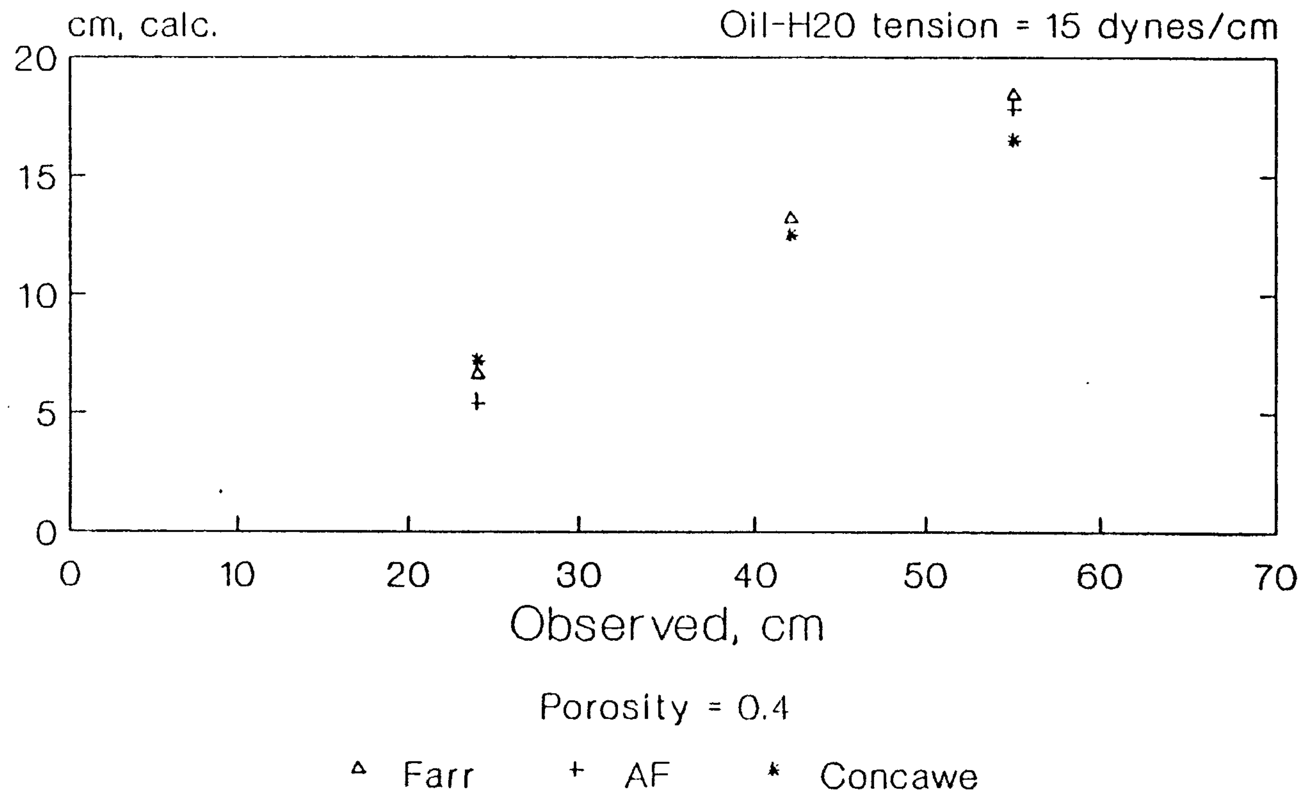


Figure 13. Shaw AFB SC Well MW 505
Observed vs Calculated Thickness

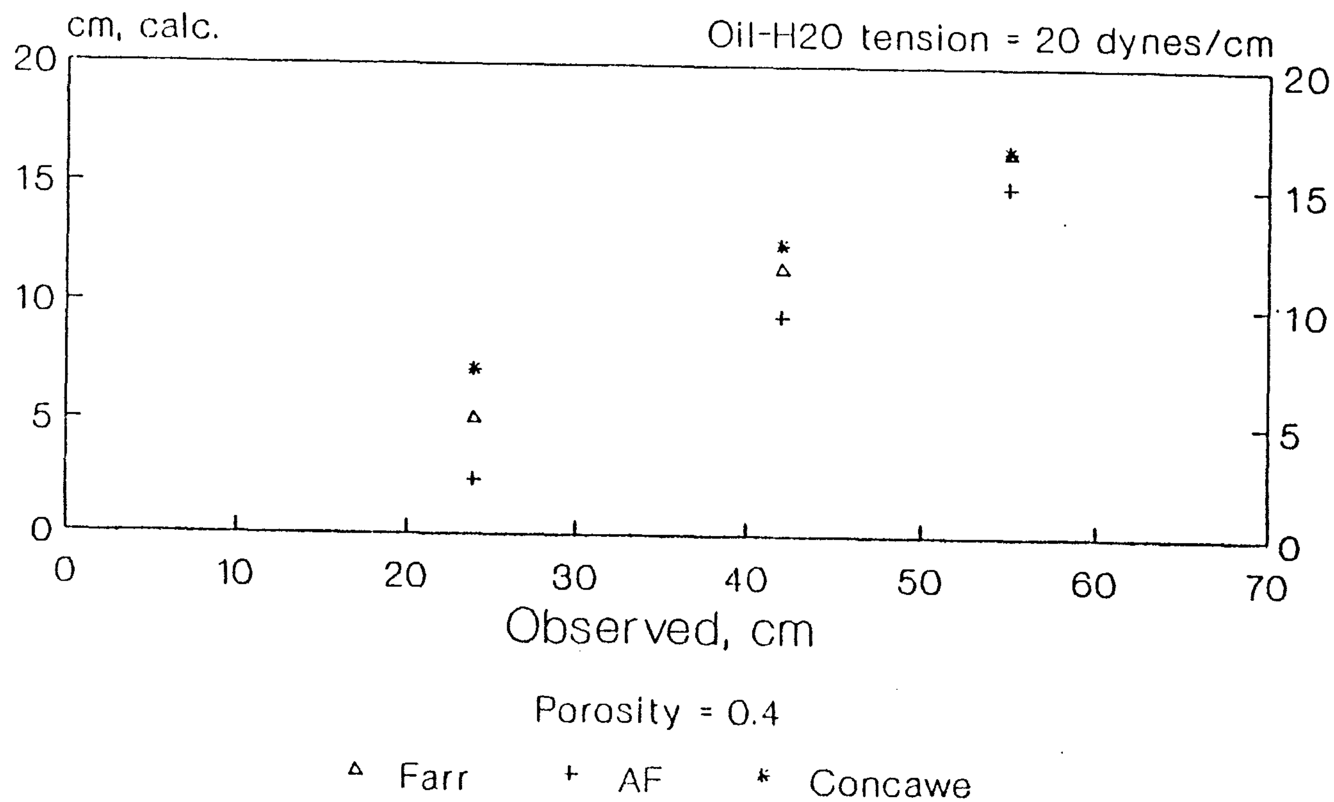


Figure 14. Shaw AFB SC Well MW 505
Impact of Porosity (0.25) on Thickness

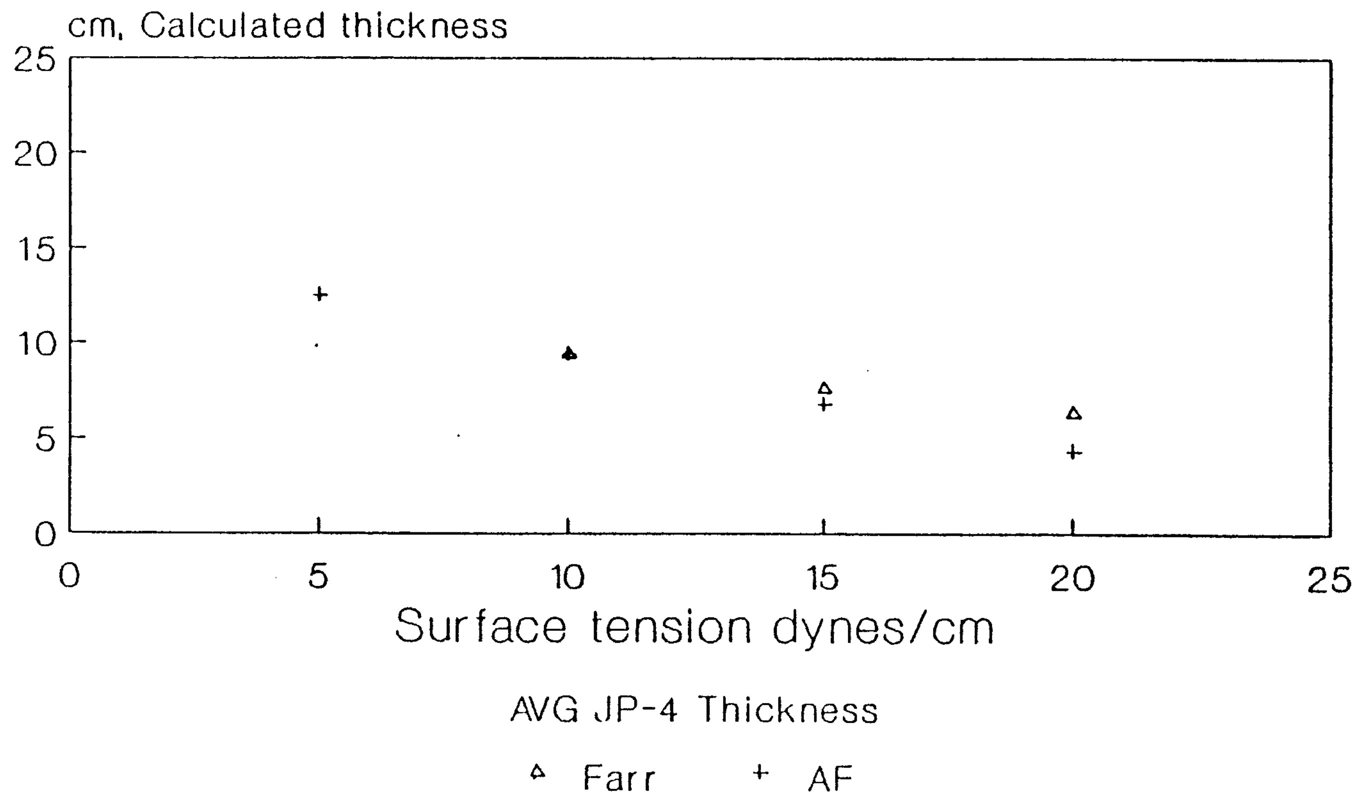


Figure 15. Shaw AFB SC Well MW 505
Impact of Porosity (0.3) on Thickness

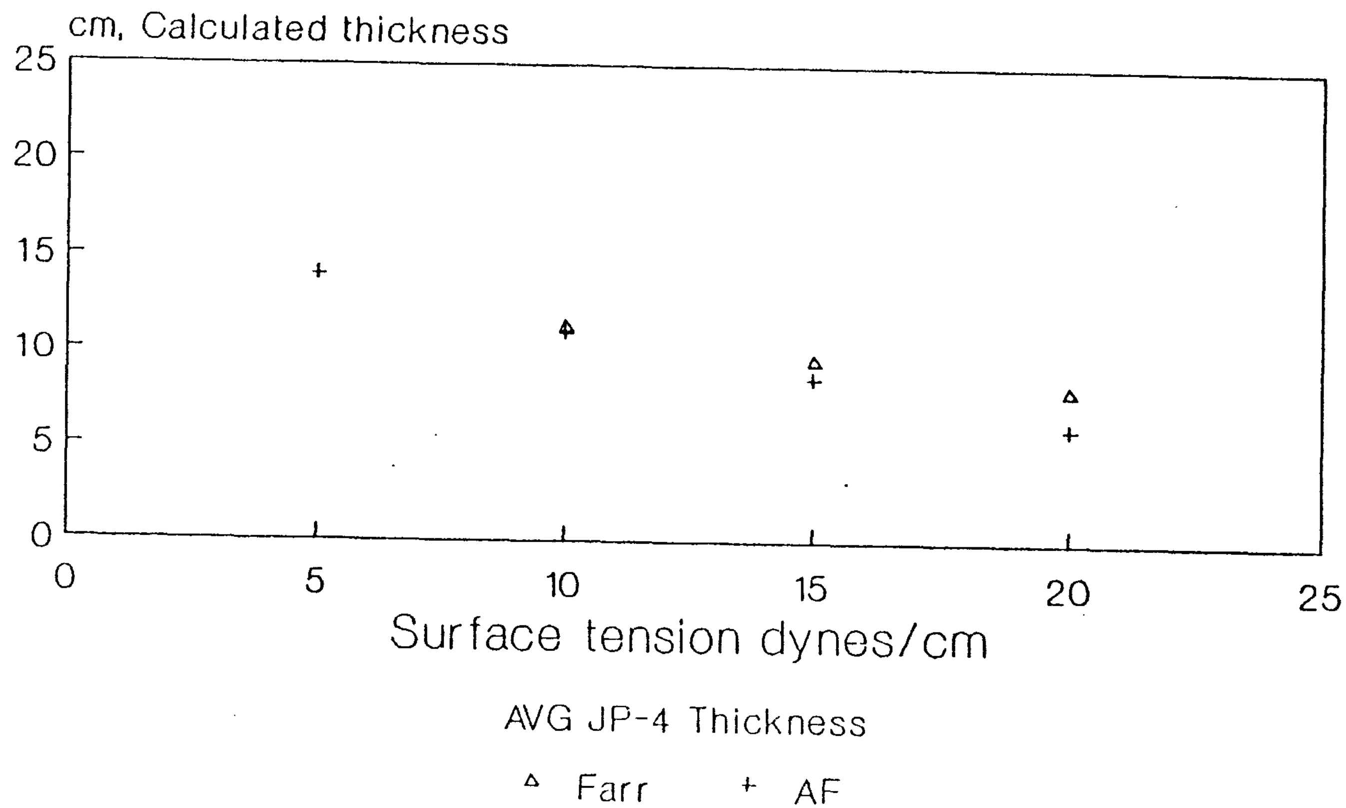


Figure 16. Shaw AFB SC Well MW 505 Impact of Porosity (0.4) on Thickness

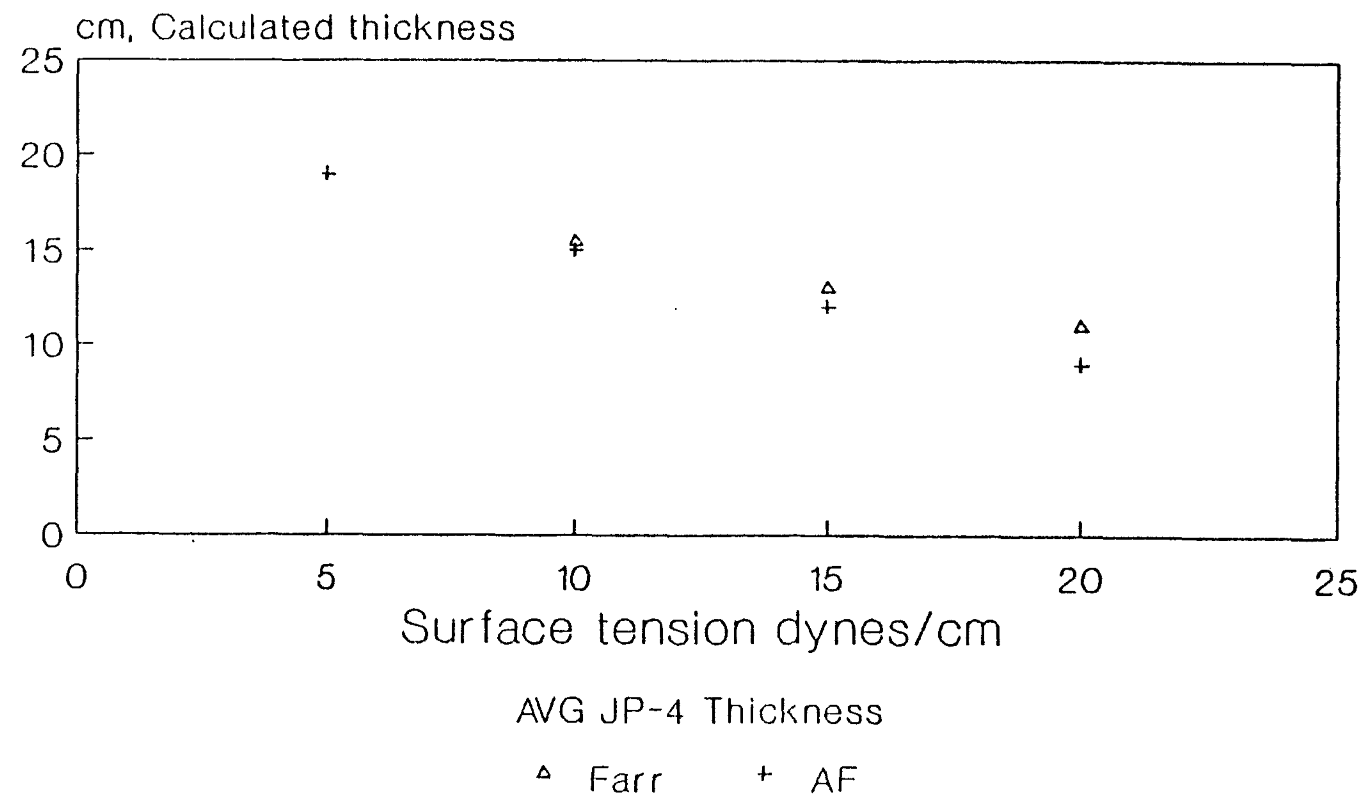


Figure 17. Shaw AFB SC Well MW 505
Impact of Porosity (0.45) on Thickness

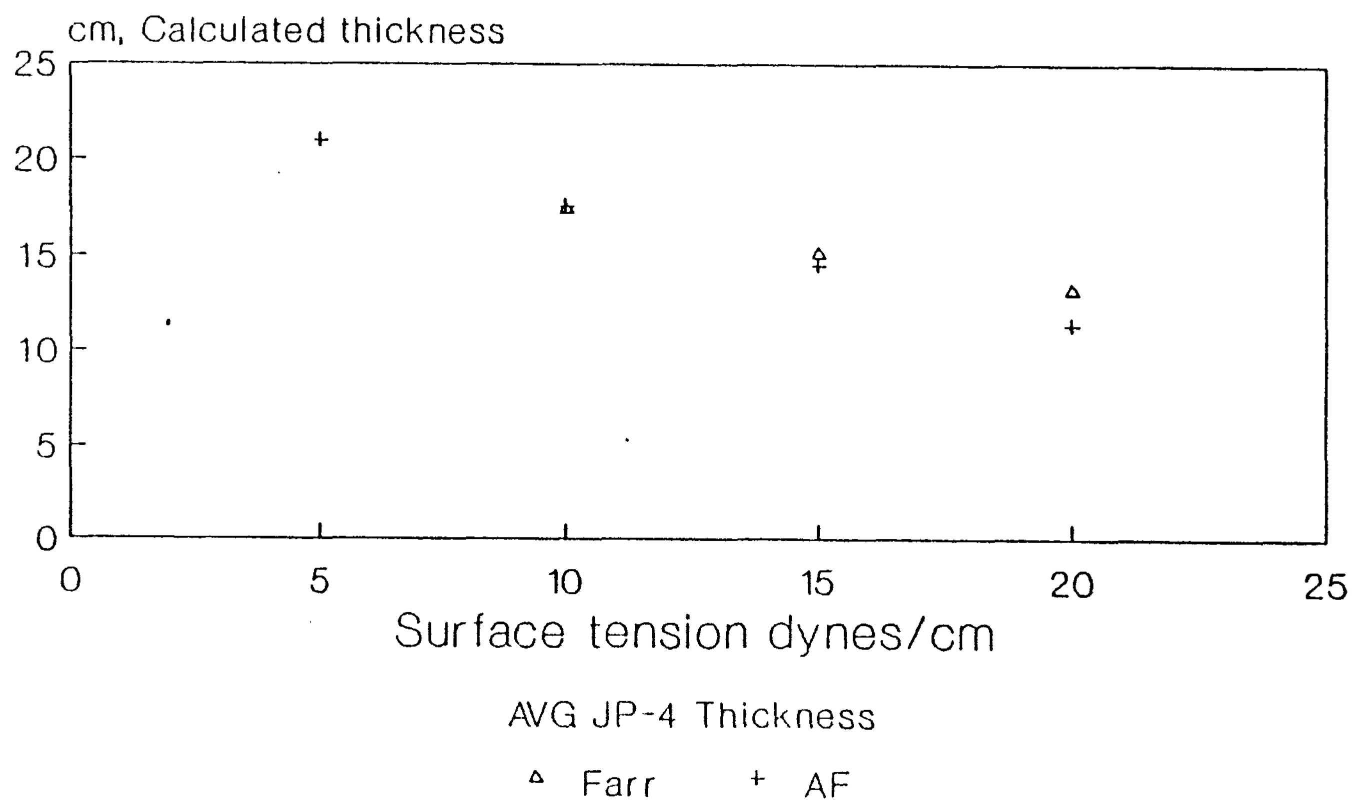


TABLE 8. OBSERVED VS CALCULATED FUEL THICKNESS, WELL PZ608

SHAW AFB SC WELL PZ608	Fuel Thickness CM Observed low = 23.5 Calculated Value	Fuel Thickness CM Observed Avg = 54.2 Calculated Value	Fuel Thickness CM Observed High = 76.2 Calculated Value
Porosity = 0.25			
Farr at 20 dynes/cm	2.4	9.1	14.2
Farr at 15	3.4	11.0	15.8
Farr at 10	4.9	12.4	17.8
AF at 20	-.2	7.4	12.9
AF at 15	2.2	9.9	15.4
AF at 10	4.9	12.5	18.0
AF at 5	7.4	15.1	20.6
CONCAWE	7.0	16.2	22.8
Porosity = 0.3			
Farr at 20	3.7	12.2	18.4
Farr at 15	4.4	13.0	19.4
Farr at 10	6.2	15.3	21.6
AF at 20	1.7	10.9	17.5
AF at 15	5.2	14.4	21.0
AF at 10	6.2	15.4	21.9
AF at 5	8.4	17.6	24.1
Porosity = 0.4			
Farr at 20	4.9	16.2	24.4
Farr at 15	6.4	17.9	26.5
Farr at 10	8.3	20.2	28.8
AF at 20	2.3	14.6	23.4
AF at 15	6.0	17.4	26.2
AF at 10	8.3	20.5	29.4
AF at 5	11.1	23.4	32.3
Porosity = 0.45			
Farr at 20	5.8	18.5	27.8
Farr at 15	7.4	20.5	30.0
Farr at 10	9.3	22.8	32.5
AF at 20	3.2	17.0	26.9
AF at 15	6.2	20.0	30.0
AF at 10	9.3	23.2	33.0
AF at 5	12.4	26.2	36.1

Figure 18. Shaw AFB SC Well PZ608
Observed vs Calculated Thickness

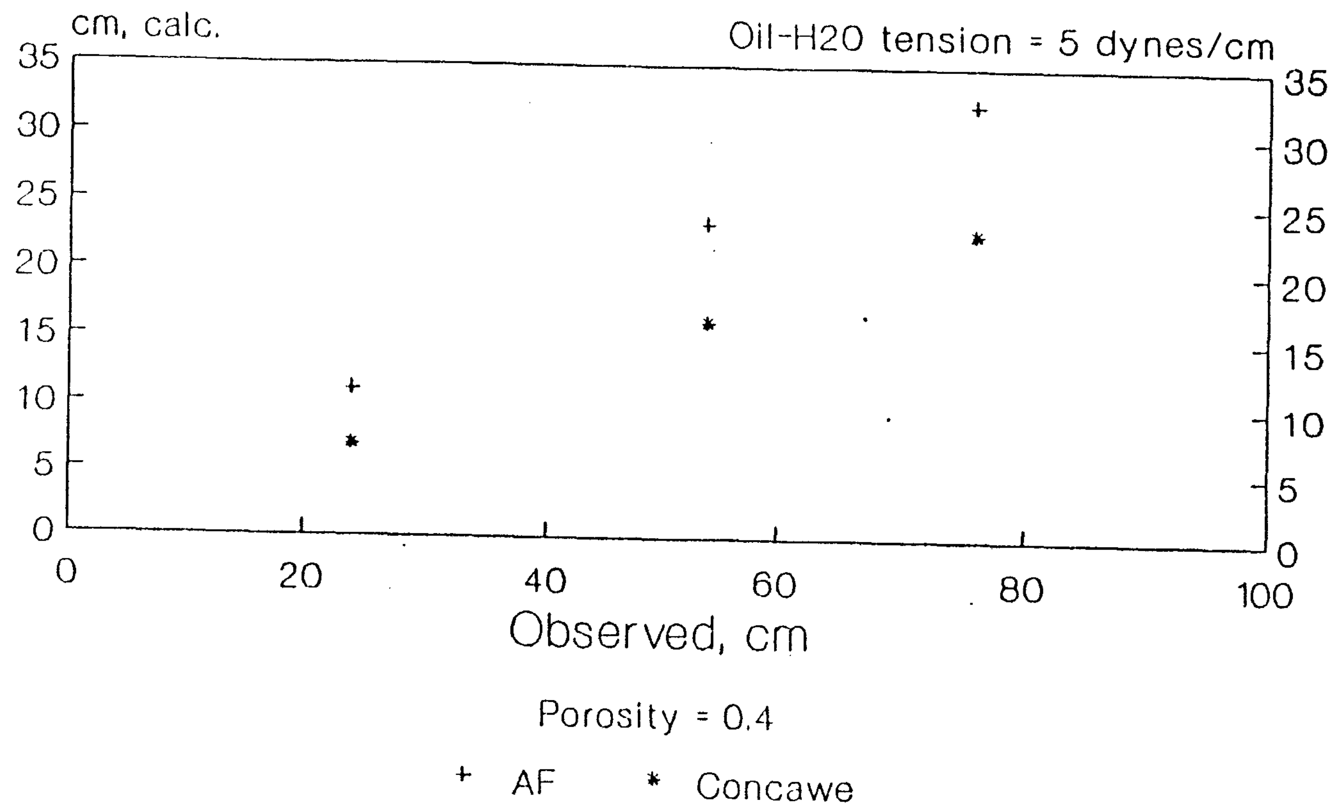


Figure 19. Shaw AFB SC Well PZ608
Observed vs Calculated Thickness

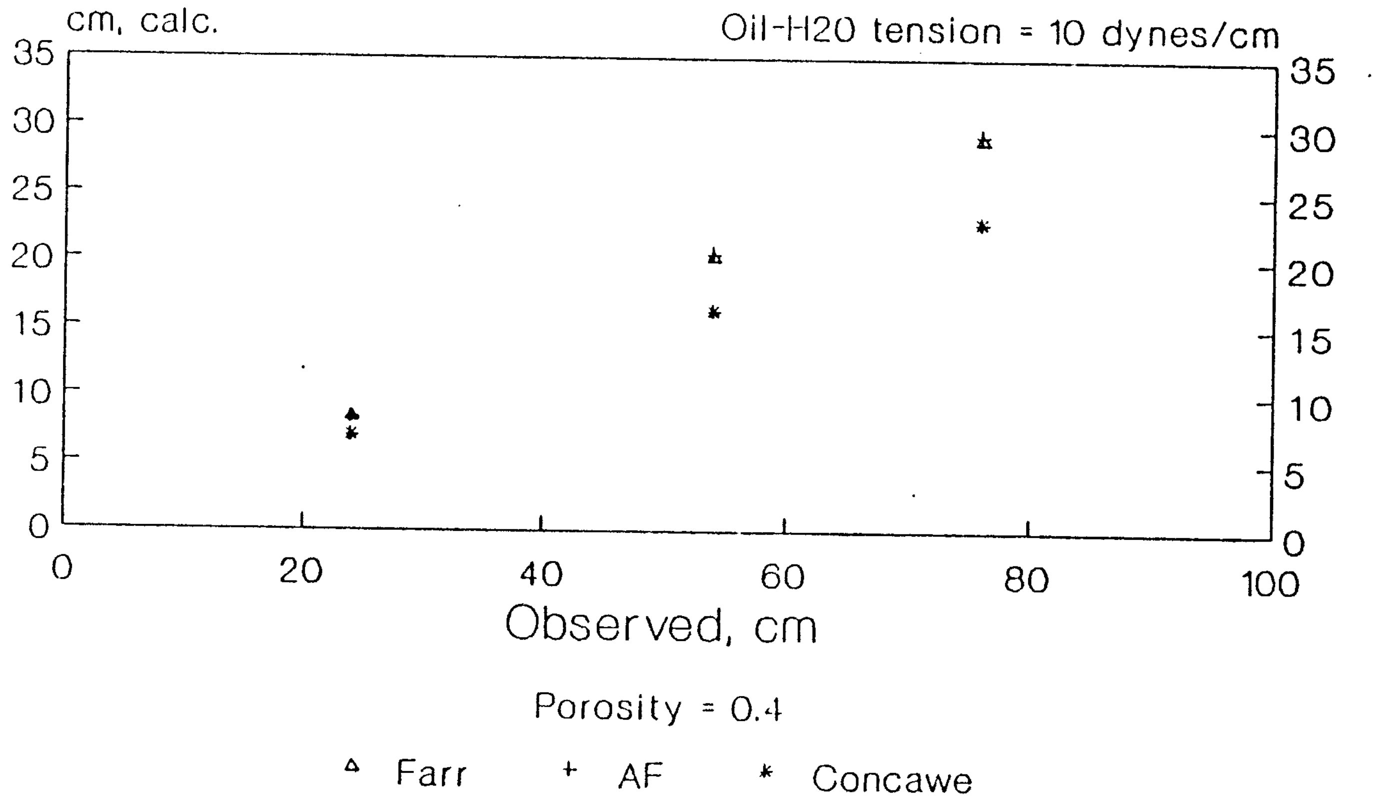


Figure 20. Shaw AFB SC Well PZ608
Observed vs Calculated Thickness

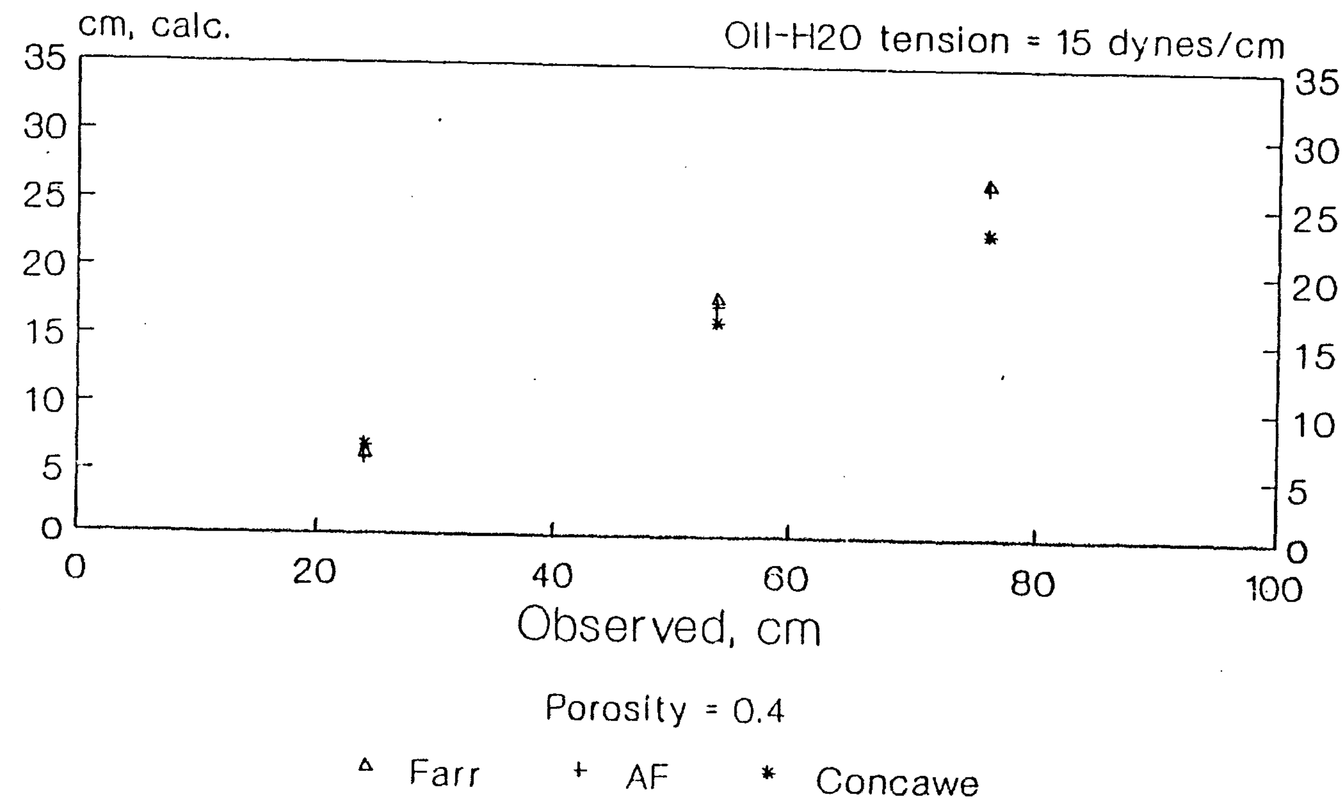


Figure 21. Shaw AFB SC Well PZ608
Observed vs Calculated Thickness

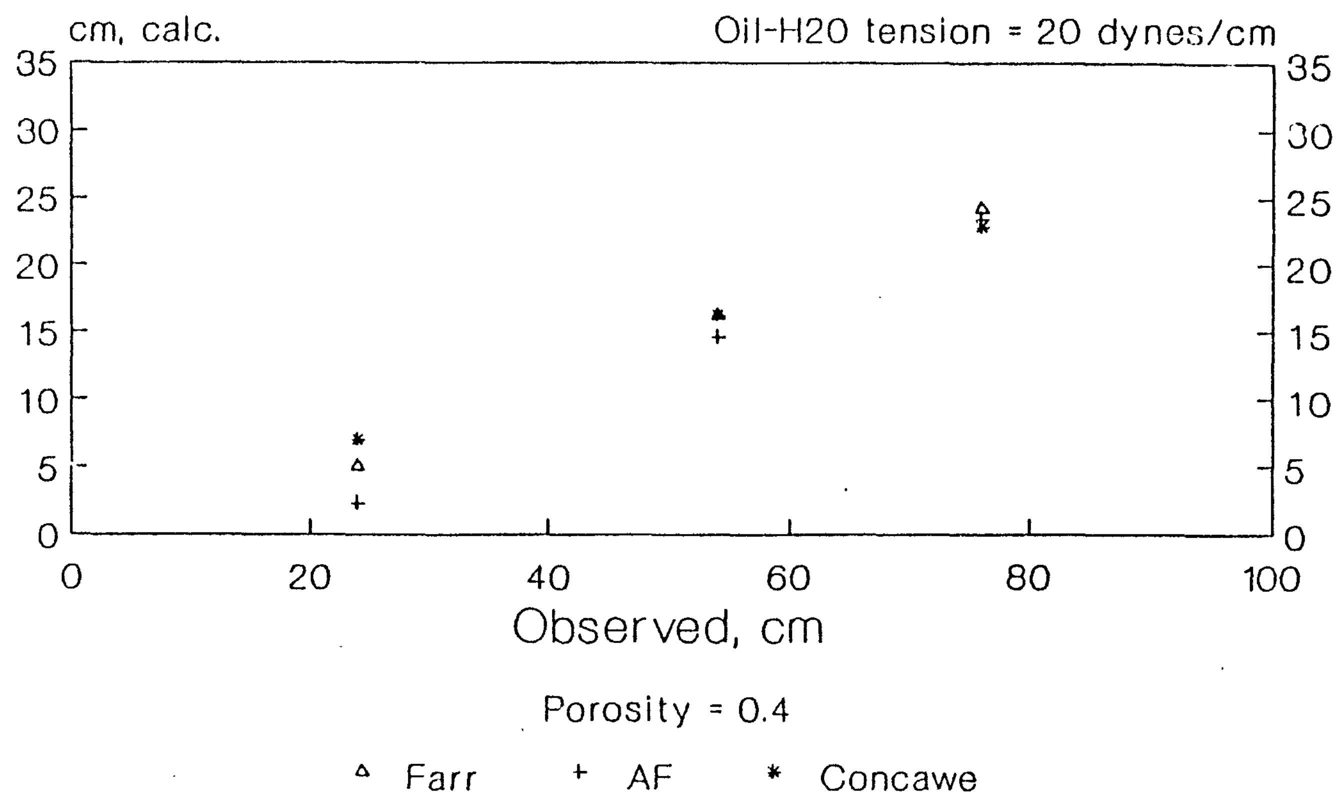


Figure 22. Shaw AFB SC Well PZ608
Impact of Porosity (0.25) on Thickness

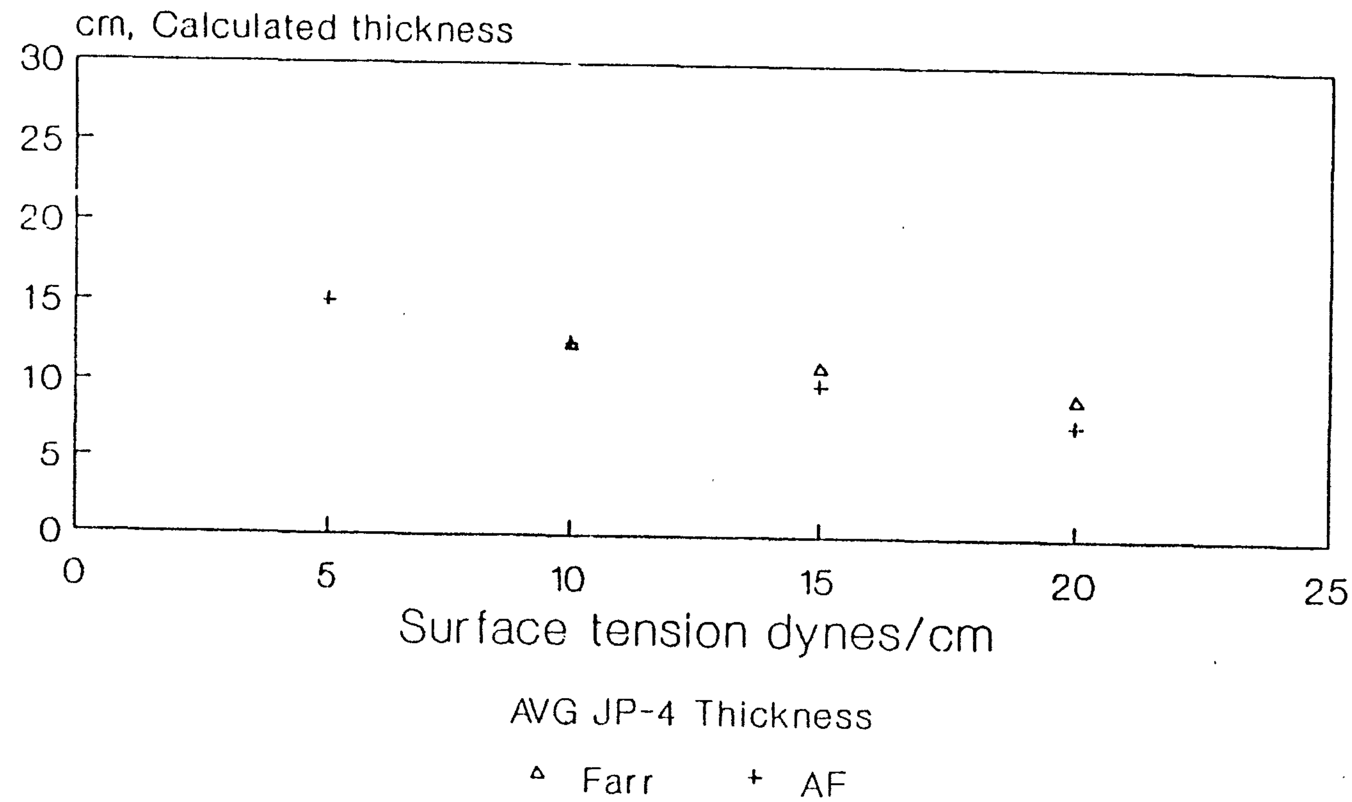


Figure 23. Shaw AFB SC Well PZ608
Impact of Porosity (0.3) on Thickness

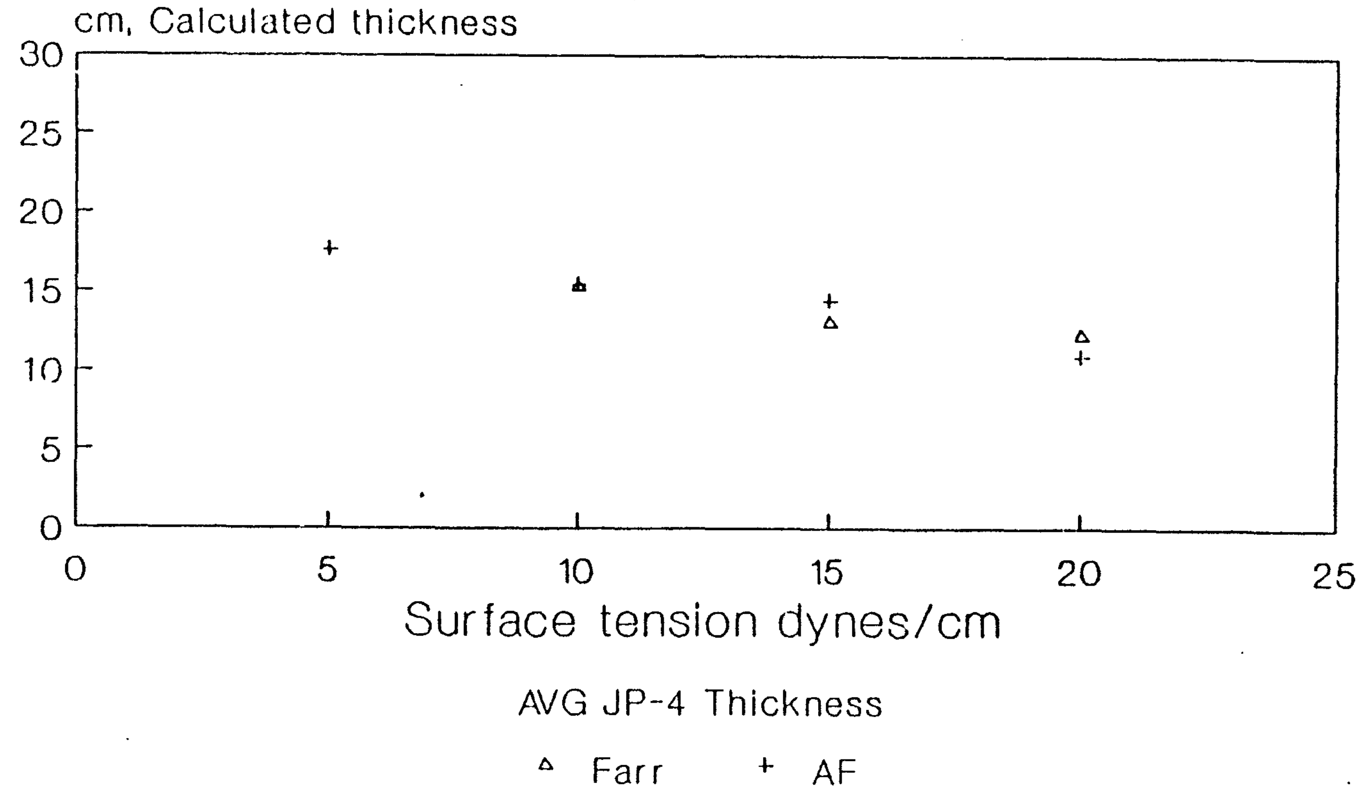


Figure 24. Shaw AFB SC Well PZ608 Impact of Porosity (0.4) on Thickness

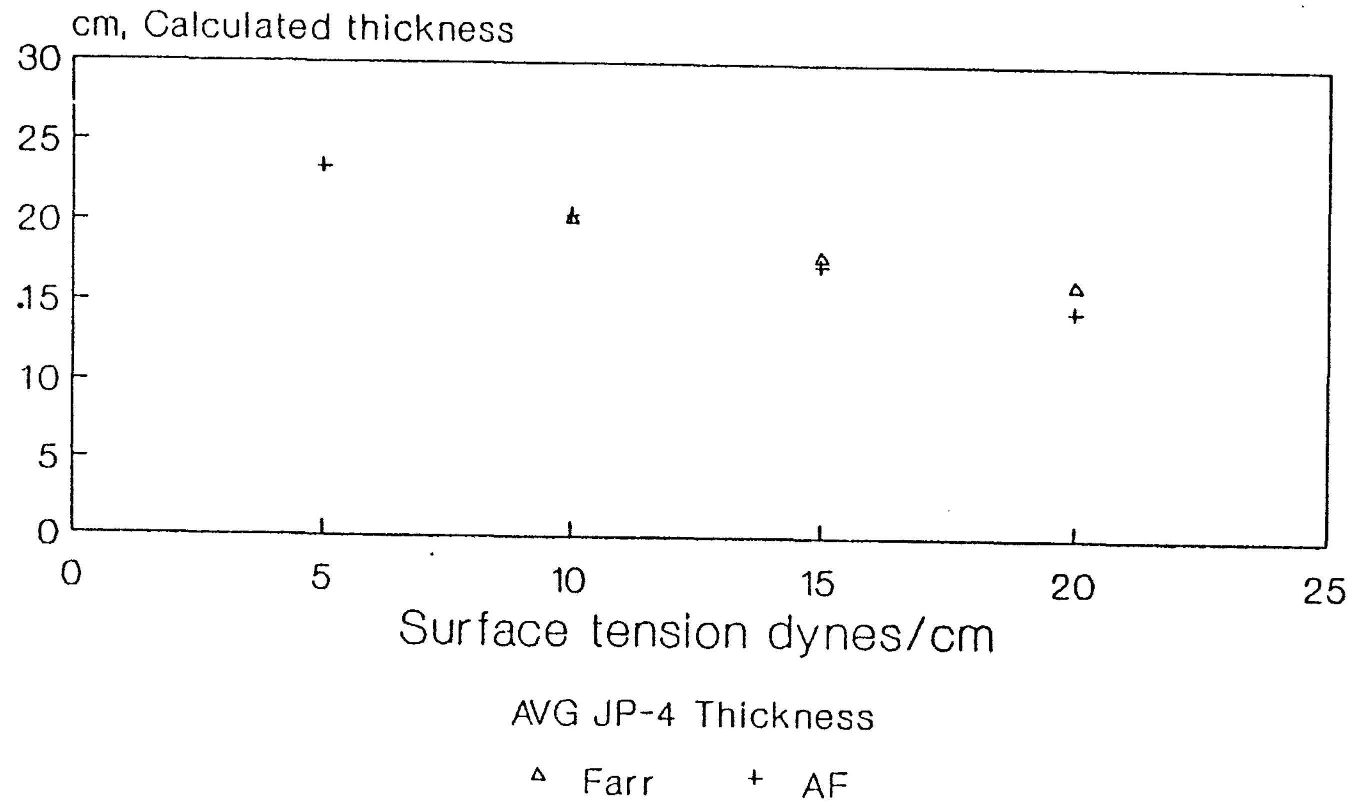


Figure 25. Shaw AFB SC Well PZ608 Impact of Porosity (0.45) on Thickness

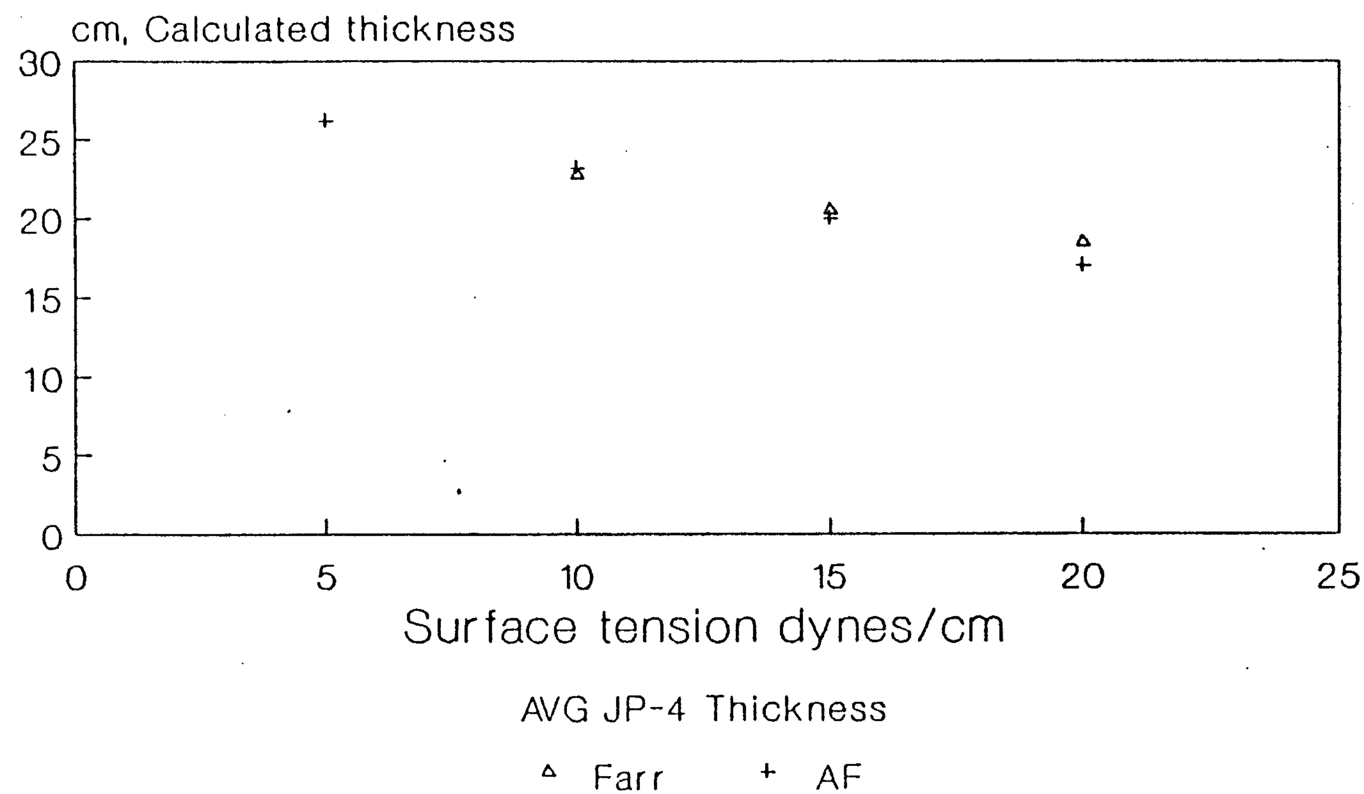


TABLE 9. OBSERVED VS CALCULATED FUEL THICKNESS, WELL PSPZ2

SHAW AFB SC Well PSPZ2	Fuel Thickness CM Observed low = 42.7 Calculated Value	Fuel Thickness CM Observed Avg = 52.7 Calculated Value	Fuel Thickness CM Observed High = 58.8 Calculated Value
Porosity = 0.25			
Farr at 20 dynes/cm	6.5	8.7	10.1
Farr at 15	7.8	10.2	11.7
Farr at 10	9.6	12.0	13.6
AF at 20	4.6	7.0	8.6
AF at 15	7.0	9.6	11.1
AF at 10	9.7	12.2	13.6
AF at 5	12.2	14.7	16.2
CONCAWE	12.8	15.7	17.6
Porosity = 0.3			
Farr at 20	10.9	13.9	15.2
Farr at 15	11.8	14.7	15.5
Farr at 10	12.4	15.3	17.1
AF at 20	6.0	9.2	11.0
AF at 15	9.6	12.6	14.5
AF at 10	11.3	14.3	16.2
AF at 5	14.2	17.2	19.1
Porosity = 0.4			
Farr at 20	11.8	15.5	17.8
Farr at 15	13.6	17.5	19.8
Farr at 10	15.7	19.7	22.0
AF at 20	11.9	15.6	18.7
AF at 15	12.9	16.9	19.4
AF at 10	15.9	20.0	22.4
AF at 5	18.8	22.9	25.3
Porosity = 0.45			
Farr at 20	13.6	17.8	20.4
Farr at 15	15.5	19.8	22.4
Farr at 10	17.7	22.2	24.8
AF at 20	11.8	16.3	19.0
AF at 15	14.9	19.4	22.1
AF at 10	17.8	22.5	25.2
AF at 5	21.0	25.6	28.3

Figure 26. Shaw AFB SC Well PSPZ2 Observed vs Calculated Thickness

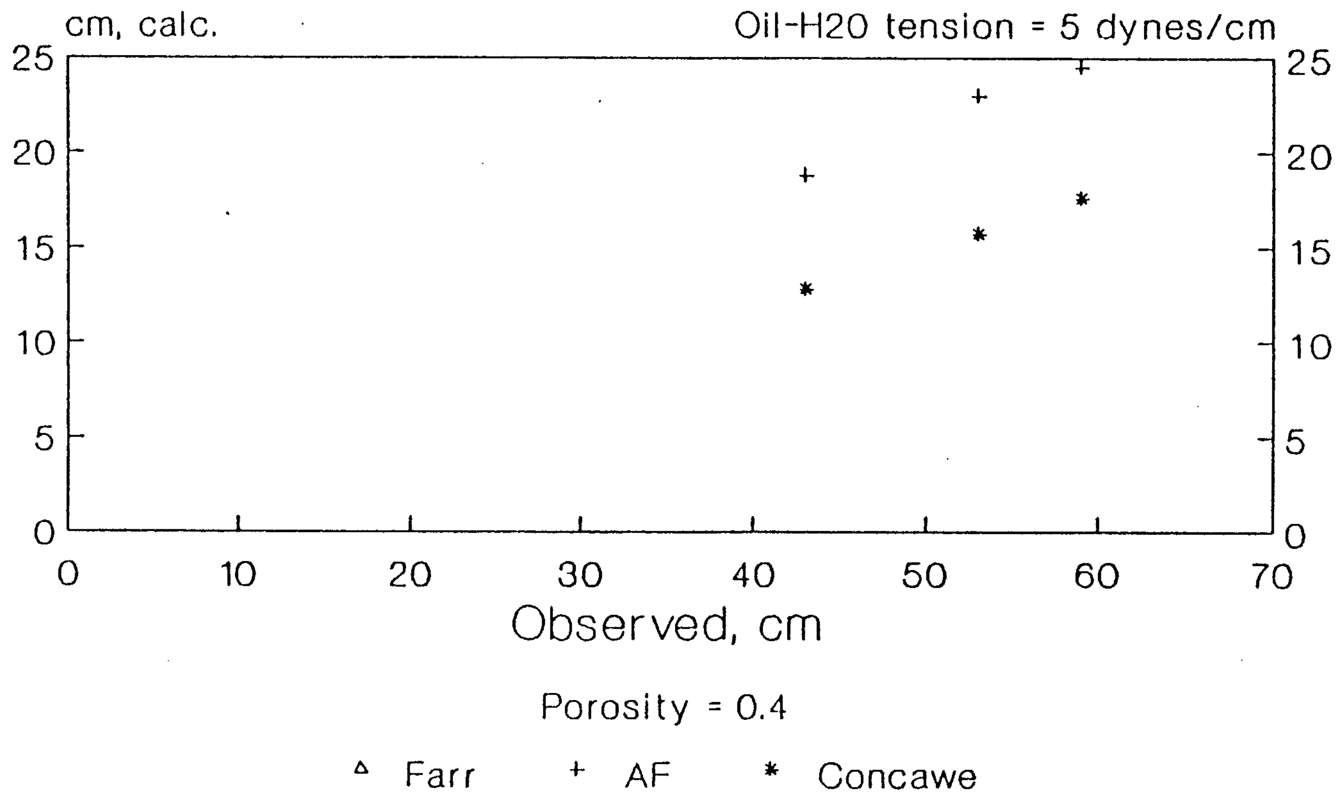


Figure 27. Shaw AFB SC Well PSPZ2
Observed vs Calculated Thickness

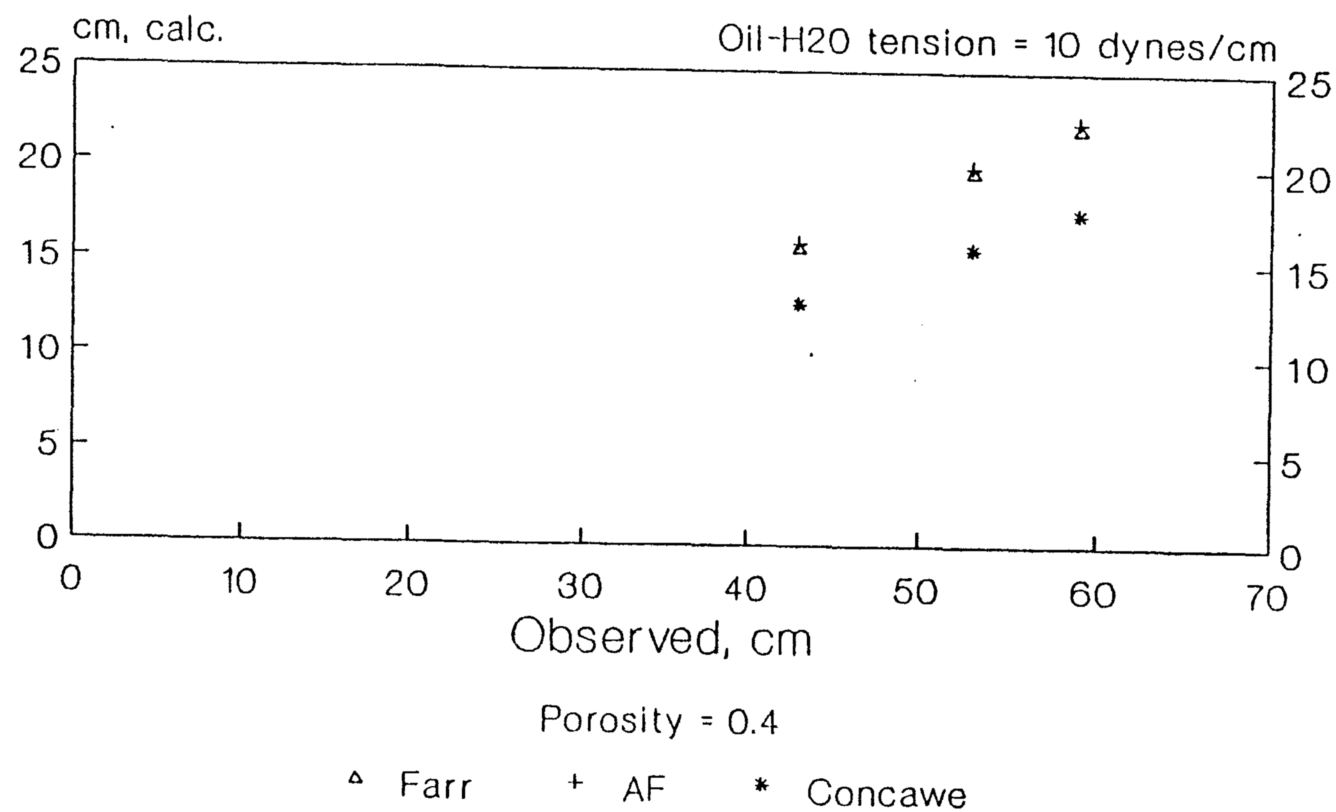


Figure 28. Shaw AFB SC Well PSPZ2
Observed vs Calculated Thickness

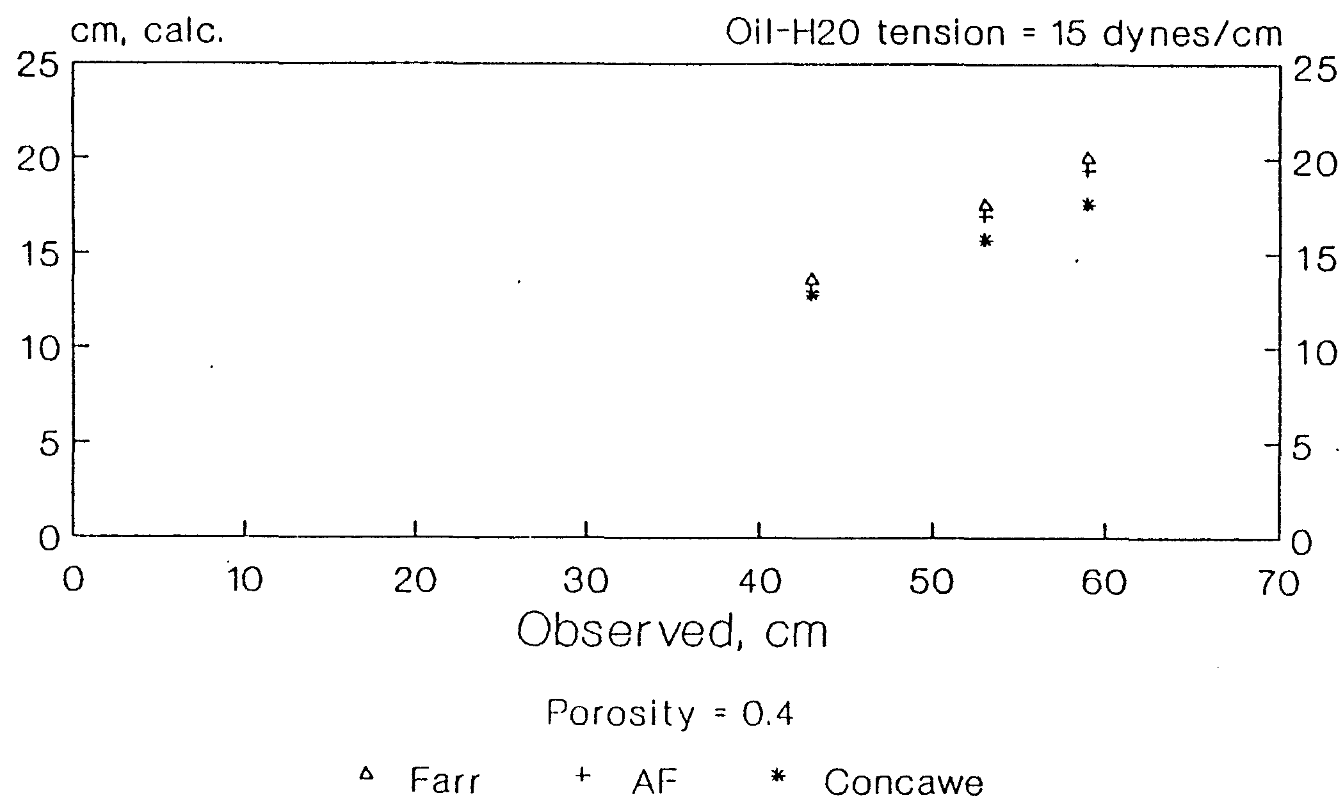


Figure 29. Shaw AFB SC Well PSPZ2
Observed vs Calculated Thickness

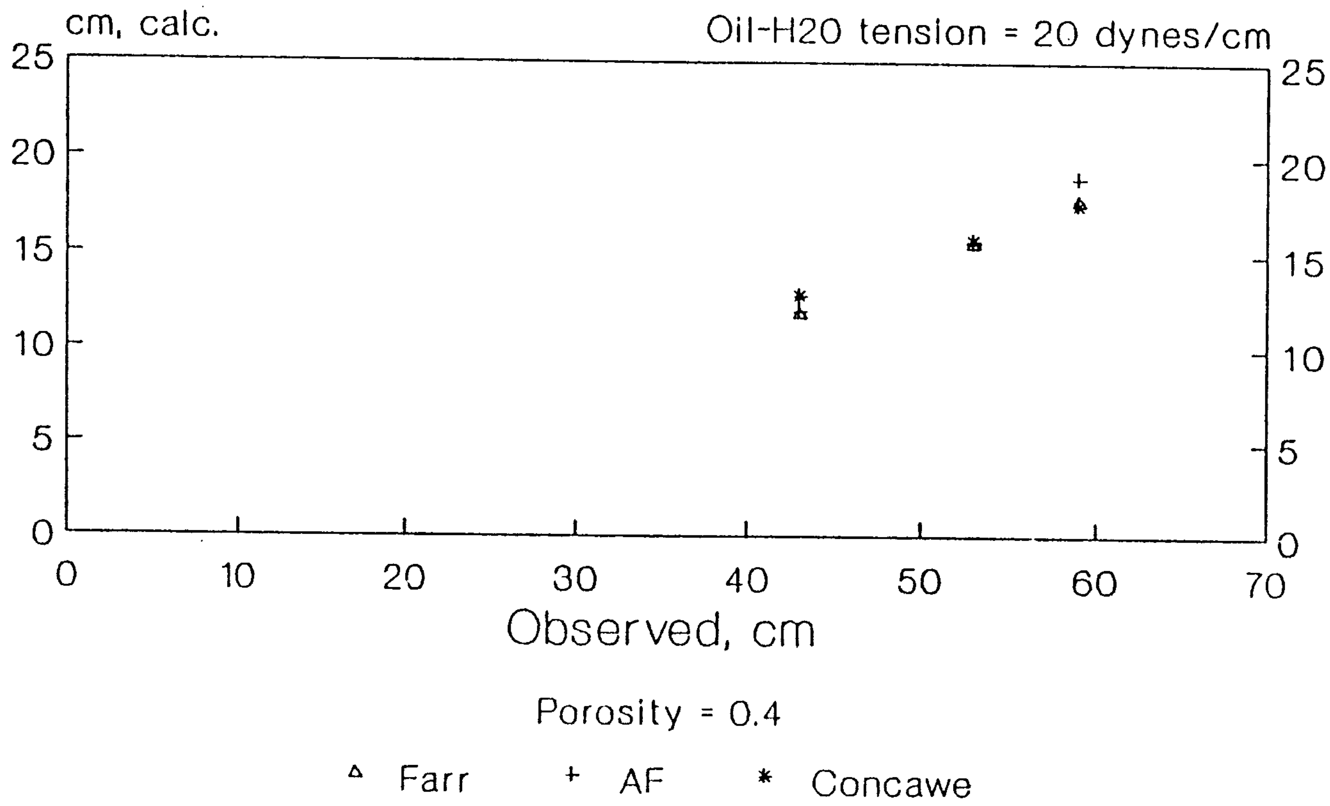


Figure 30. Shaw AFB SC Well PSPZ2 Impact of Porosity (0.25) on Thickness

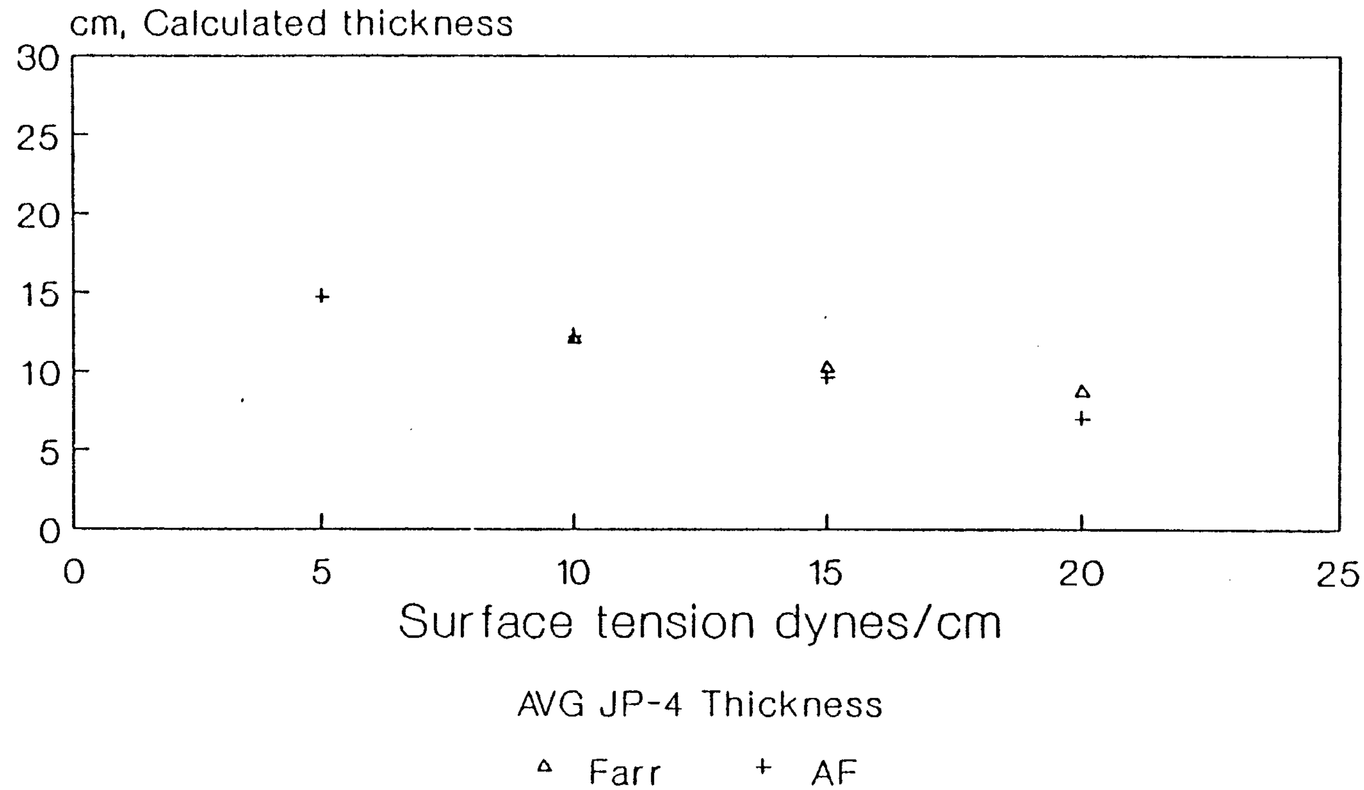


Figure 31. Shaw AFB SC Well PSPZ2 Impact of Porosity (0.3) on Thickness

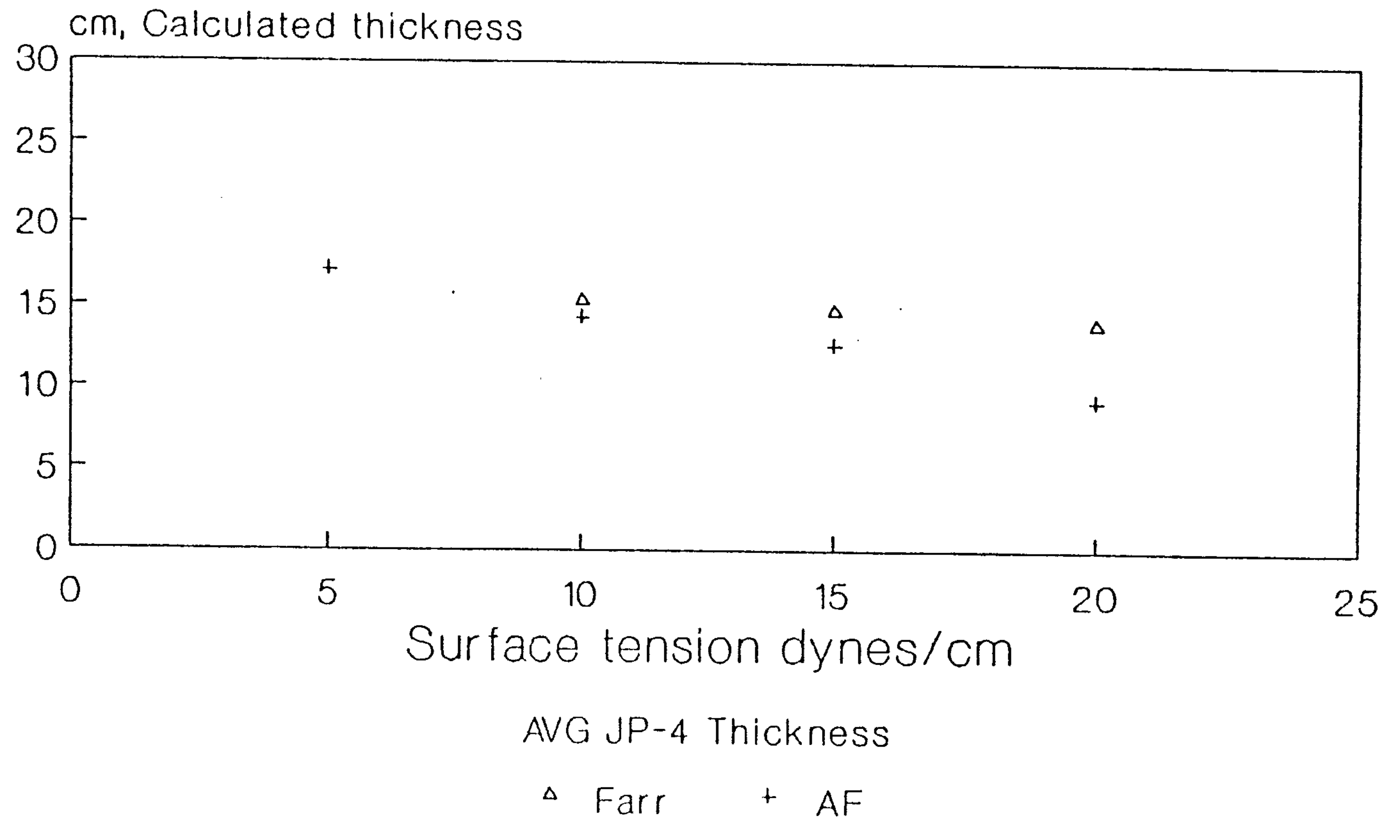


Figure 32. Shaw AFB SC Well PSPZ2
Impact of Porosity (0.40) on Thickness

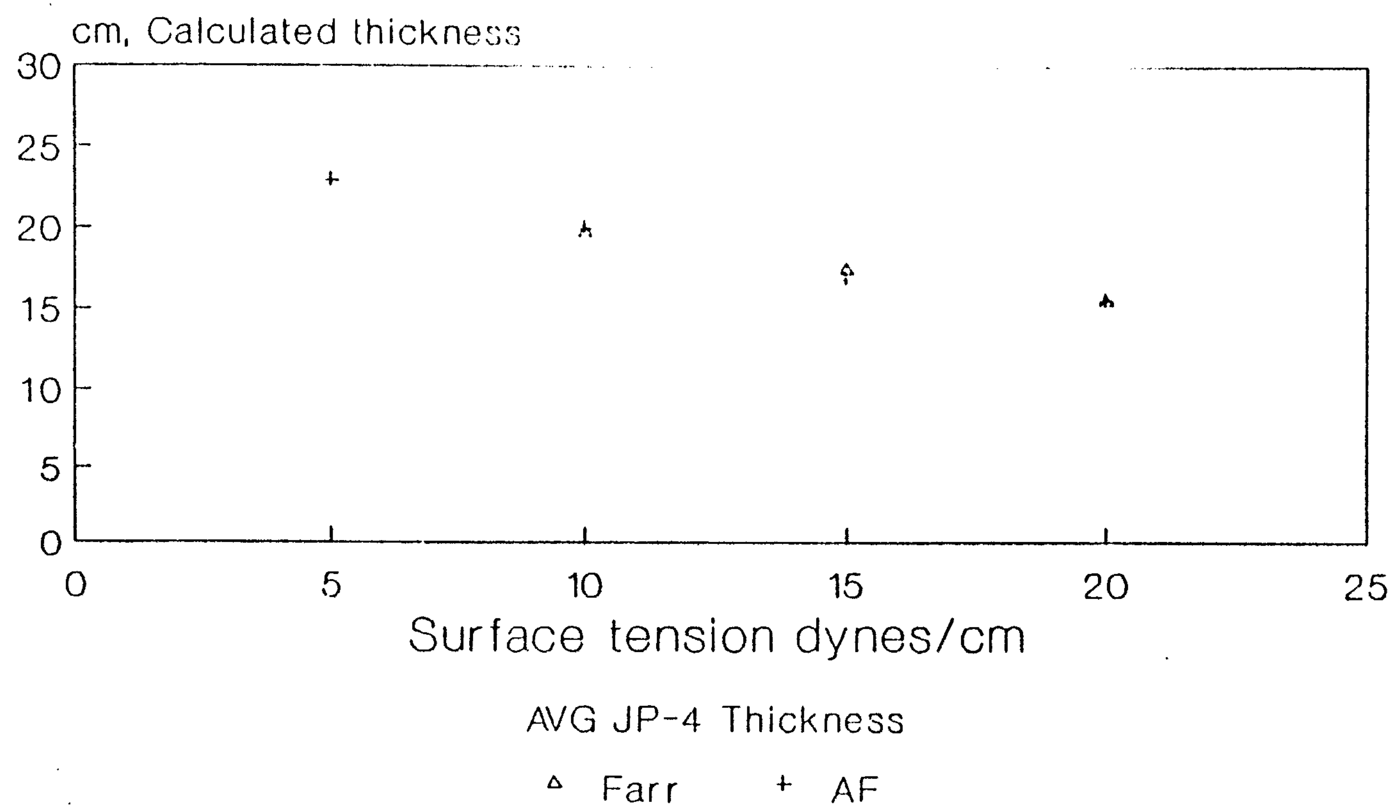
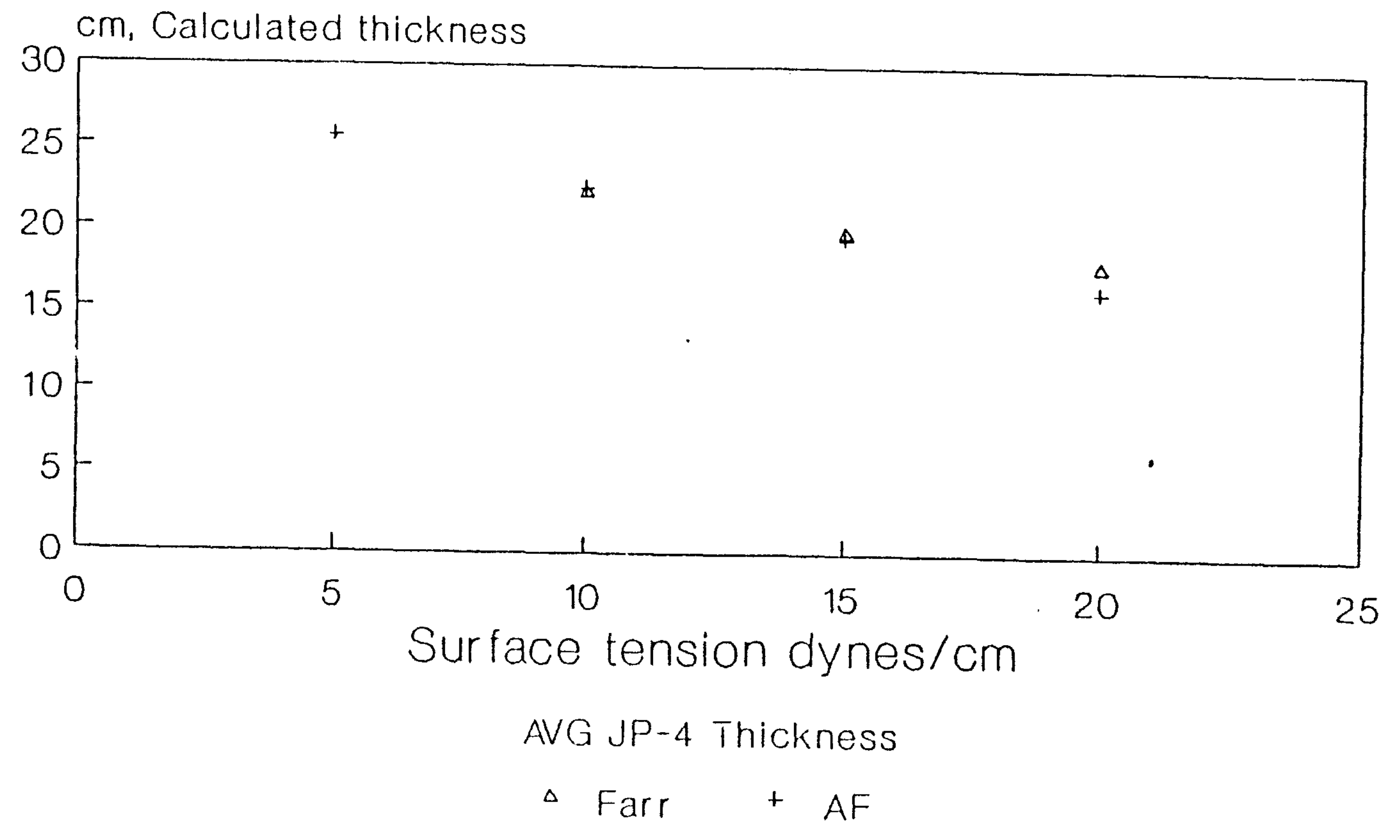


Figure 33. Shaw AFB SC Well PSPZ2 Impact of Porosity (0.45) on Thickness.



HOMESTEAD AFB FL

SITE HISTORY

Homestead AFB FL is located at the extreme Southeastern tip of Florida. In May 1982 JP-4 fuel was discovered in a drainage canal near the JP-4 storage area. The source of the JP-4 was identified to be a corroded purge line near fuel pump station nine. In November 1984, the Phase II investigation of the Installation Restoration Program (IRP) confirmed the presence of a floating layer of fuel at this site. Four monitoring wells were developed as part of the Phase II proceedings, however only one well (I-18) has ever had free product appear. An oil-water recovery system was installed at well I-18 in November 1985 to recover floating JP-4, however, the recovery efforts have been unsuccessful. The plume of JP-4 is thought to encompass approximately 160,000 square feet floating on the water table approximately six feet below grade. The Air Force IRP contractor has not given a volume estimation of the amount of fuel present at this location. (1988 Homestead AFB IRP report).

GEOLOGY

Homestead AFB is underlain by Miami Oolite and the Fort Thompson geologic formations. The vadose zone is characterized as sandy silt (USC code ML) down to approximately three feet below grade. The saturated zone is shown to be a combination of silts/fractured lime rock to weathered lime rock to highly fractured limestone. The saturated zone is known as the Biscayne Aquifer, which underlies most of Southeastern Florida and has been designated as a sole source aquifer for Southeastern Florida. Homestead AFB lies within the recharge zone of the Biscayne Aquifer.

No well log or particle size distribution (PSD) was available for well I-18, however a well log was available for MW3S, which was installed in August 1986, within twenty feet of I-18 (see HOMESTEAD appendix). Through assessment of the well log for MW3S and a review of similar geologic materials the following SOILPROP input was made for the zone of interest (water table - JP-4 interface): 50% fines, 40% fine sand, and 10% medium sand.

OBSERVED JP-4 LEVELS

Civil Engineering personnel conducted weekly measurements of the JP-4 thickness and depth to water table at well I-18 for

sixteen months (see HOMESTEAD appendix). The variability in depth to water table was practically non-existent, with the range from low to high levels differing by only twenty cm over the sixteen months of monitoring. This could indicate a stable aquifer with little influence in this particular region from tidal action or salt water intrusion. However, the variability in observed JP-4 thicknesses was large, from 17-63 cm. The average JP-4 thickness over the entire monitoring period was 37 cm. No defined trends could be ascertained as to seasonal changes compared to observed fuel thickness. No remediation efforts were conducted during the period of fuel thickness and depth to water table monitoring.

COMPUTED JP-4 THICKNESS

The following thicknesses of JP-4 were calculated based on a SOILPROP Pd^{ow} value 7.44 cm and a Sr value of 0.278 being generated from the well log assessment (porosity = 0.4, oil-water interfacial tension = 15 dynes/cm).

TABLE 10. OBSERVED VS. CALCULATED JP-4 THICKNESS, HOMESTEAD

	Thickness (cm)		
Method	low	Avg	high
Observed	17.0	37.0	63.0
Farr	1.5	5.5	11.3
AF	0.5	6.5	15.6
Concawe	5.1	11.0	18.8

Figure 34 on the following page illustrates the above values.

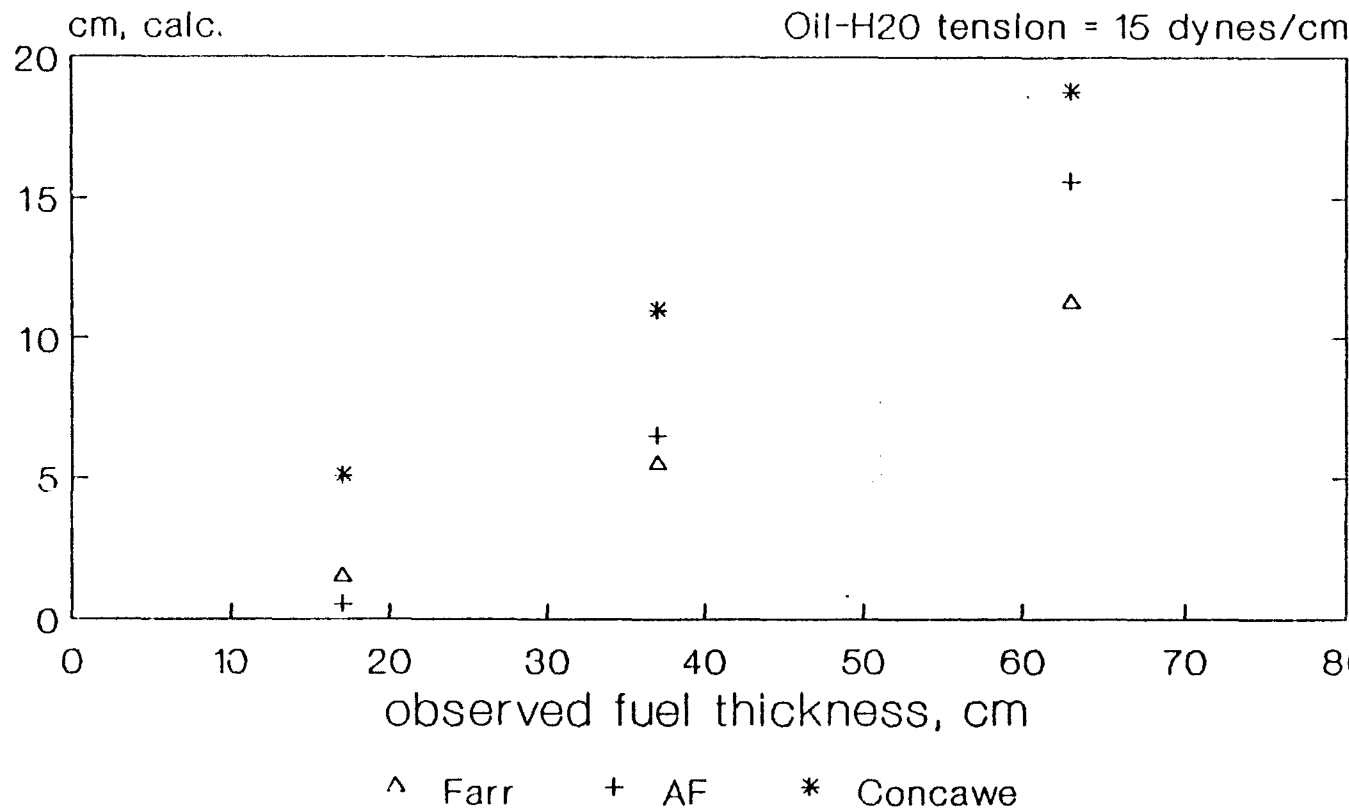
SITE CONCLUSIONS

The calculated fuel thicknesses at this site should be contemplated as having a large degree of uncertainty associated with them. The SOILPROP inputs contain elements of uncertainty on the part of the researcher interpreting the well logs and assigning particle size distributions (PSD). This task could easily lead to plus or minus 50% error in the computed Pd^{aw} values.

At this installation, the Concawe equation consistently produced answers well above the Farr and AF equations. Part of the range in answers may be explained in that the Concawe equation does not take into account the geologic formation, whereas the AF and Farr equations have corrections for porosity, and importantly at this site, specific retention (Sr), for which SOILPROP assigned a value of almost 28%. This alone explains most of the range in the values generated by the three equations.

However, at this location, the Concawe equation may be the best estimator of the actual fuel thickness on the aquifer, due to the uncertainty attached to the AF and Farr equation parameters of porosity, oil-water interfacial tension, and PSD data.

Figure 34. Homestead AFB FL Well I-18 Observed vs Calculated Thickness



LANGLEY AFB VA

SITE HISTORY

Base and contractor personnel discovered a floating layer of JP-4 at Langley AFB in 1982 as part of a phase II Installation Restoration Program (IRP) investigation. The JP-4 contaminated site is known as IRP site 4 (see Appendix 3, LANGLEY, for a map of the site and well locations). IRP site 4 is near a set of underground storage tanks which were abandoned in 1963. In addition, in 1982 underground fuel lines were also discovered leaking in the immediate area. The floating layer of JP-4 is estimated to cover an area of approximately four acres, at a depth ranging from 2.5 to 6 feet. The floating product at this installation is monitored through a network of eleven wells but free product appears in only four, wells 2, 7, 11, and 13. See appendix 3 for tables of the observed values of JP-4 thickness and depth to water table readings. During a 1986-1987 Air Force JP-4 recovery effort, 2000 gallons of JP-4 was recovered from IRP site 4. The current AF IRP contractor has yet to render an estimate of how much JP-4 remains at this location. A pump and treat recovery system is in the design stage for long-term recovery and restoration of this site. (1989 Langley AFB IRP report).

GEOLOGY

The unsaturated zone at IRP site 4 is characterized as silty clay with some fine gravel present. The saturated zone is described as fine sands and silt, grading to medium sands with abundant shell fragments present. All four of the wells with free product at this site had detailed well logs available for assessment. In addition, a May 1990 particle size distribution (PSD) at six foot below grade was available for well OW-103, which is located approximately 150 feet from the JP-4 plume. The PSD data from OW-103 was assigned to the four wells containing free product. The water content of the PSD sample was 26.2%. After assessment of the PSD data and review of the well logs, the following input was made into SOILPROP: 28% fines, 63% fine sand, 4% medium sand, 1% coarse sand, and 4% fine gravel.

The hydrogeology of this site is extremely variable, due to a number of factors, including an oceanic tidal influence and a railroad bed running parallel to the site. The railroad bed is thought to act as a barrier to horizontal groundwater flow through the site.

OBSERVED JP-4 LEVELS

Air Force bioenvironmental engineering personnel conducted weekly measurements of the JP-4 floating layer March through December 1989. See Appendix 3, LANGLEY for tables of the observed JP-4 thickness and graphical illustrations of the data. The variability of the observed fuel thickness and depth to the water table at this location was the greatest of the six Air Force bases included in this study. It is presumed the tidal influence at this site causes the large differences in observed fuel thickness and depth to the water table. For example, the range from low to high water table differed by 114 cm in well 2, but only 64 cm in Well 7, which is located only 250 feet from well 2.

The observed fuel thickness in the wells also changed dramatically over time, ranging from low readings of 0.3 cm (near the limit of detection of the monitoring instrument), to a high reading of 38.4 cm, (127 fold increase). Based on data from all four wells, the average value of JP-4 observed over the entire monitoring period for this site was 15.5 cm.
The difference in the average values of JP-4 found between the four wells was 28 cm, which indicates the variability in the JP-4 layer over the relatively short distance of 500 feet. The difference of fuel level observed within each well was also

large as indicated in the table below:

TABLE 11. DIFFERENCES IN OBSERVED FUEL THICKNESSES - LANGLEY

Well	high (cm)	low (cm)	Difference (cm)
2	38.4	0.3	38.1
7	33.0	2.1	30.9
11	38.4	1.2	37.2
13	17.4	0.3	17.1

The impacts of the great differences in the observed JP-4 values will be explained in the next section.

COMPUTED JP-4 THICKNESS

Using the PSD data and well log inputs, SOILPROP produced an air-water capillary head (Pd^{aw}) level of 3.54 cm at a porosity of 0.4 (baseline conditions).

The following porosities were input to observe the changing Pd^{aw} fringe.

TABLE 12. POROSITY, SATURATION AND Pd^{aw} VALUES, LANGLEY AFB

Porosity	Pd^{aw} (cm)	Sr
0.27	4.20	0.184
0.35	3.71	0.225
0.4	3.54	0.248
0.45	18.2	0.269

S_r = residual saturation of water, used in the Farr equation.

See tables 13-16 for the calculated JP-4 values at the different porosities and oil-water surface tension (σ_{ow}) values.

Figures 35-59 illustrate the calculated JP-4 values at varying porosities and surface tension (σ_{ow}).

As indicated, the trend of greater calculated fuel volume with increasing porosity is apparent, except at the 0.45 level where the calculated volume decreases. Also the trend of increased calculated fuel volume with lower fuel-water surface tension is shown except at the 0.45 level. The results of the Concawe equation again show a linear relationship between the observed and calculated fuel levels. Referring to the baseline data, well 2 shows a small range of calculated values at the 13 cm level between all three equations (range of only 3.9 cm) and at the 38 cm level, a spread of 4 cm is seen again from high to low, with the Concawe result at the high end. This trend would be expected to continue with increased fuel levels in this soil type.

At this site, due to the almost complete disappearance of the fuel (at times less than 0.5 cm observed), the calculated lower level of JP-4 was ignored in two of the four wells. A general trend was observed that in times of rising water elevation, the observed fuel levels drastically decreased, almost to the point of disappearance. This principle holds with findings by Yaniga (1984).

As stated earlier a porosity of 0.45 leads to smaller calculated fuel thickness than a porosity of 0.4, but only at the higher surface tension values of 15 and 20 dynes/cm. The values between the porosities of 0.4 and 0.45 are about equal at 10 dynes/cm, and at 5 dynes/cm, the trend of increasing calculated thickness continues at the higher porosity. This may be explained by the large increase in the Pd^{aw} factor at the porosity of 0.45, when calculated in the AF and Farr equations, leads to smaller volumes due to the product of the division of the large Pd^{aw} value. This phenomenon is thought to be a factor of the soil conditions at this location, i.e. 28% fines, in that this factor did not occur at other locations.

SITE CONCLUSIONS

GEOLOGY

The calculated thickness of JP-4 fuel are highly dependent on correct geologic information being furnished for the AF and Farr equations. As stated earlier this is not a factor when using the Concawe equation. The SOILPROP inputs for this location should be considered as having a high degree of certainty attached in that the PSD data was very close to the actual contaminated area at the depth of interest. Also, well logs were available for all four wells, and they showed remarkable

consistency at the depths of interest (see LANGLEY Appendix).

POROSITY

This is the only site in this study that had an actual porosity measurement of the saturated zone available. It would appear in this case the 0.27 porosity measured on site would be the best value to use in total volume calculations, as porosity in the saturated zone should not change. However, one is cautioned in using only one porosity value for the entire field of contamination, especially at this site where the depth to water changes dramatically.

MULTIPLE MEASUREMENTS

More than any other site, the importance of multiple measurements at this location is highlighted by the fact that calculated fuel thickness changes by a factor of ten at the porosity of 0.27 and a factor of twenty at the porosity of 0.45. If fact, during times of rising water table, the observed fuel thickness practically disappears altogether. Multiple fuel measurements (at least weekly for six months) are recommended in areas that may have tidal influences.

There may be some doubts as to the use of the Farr and AF equations at this site due to the rapidly changing water table and violation of the principle of equilibrium (Farr, 1990, Lenhard & Parker, 1990). However the main thrust of this endeavor is to indicate and document the extreme variability in answers using different equations for fuel thickness as reported from various sources (Milligan, 1989). The rapidly changing water table in this instance is another major influence on the range of computed fuel thickness at this location.

FUEL SURFACE TENSION

The variability of calculated volumes is shown in the parameter of oil-water interfacial tension. This is seen at all porosities to differ four to ten cm at the average fuel level. The variability of calculated fuel levels may be minimized by knowing the approximate correct oil-water interfacial tension and using it in the Farr and AF equations. The Concawe equation appears to be closest to the AF and Farr equations at the 5 and 10 dynes/cm level. If the surface tension of the fuel under study was known to be approximately 5-10 dynes/cm, using the Concawe equation will give answers equivalent to the Farr and AF equations in this soil type.

TABLE 13. OBSERVED VS CALCULATED THICKNESS, LANGLEY WELL 2.

LANGLEY AFB VA Well 2	Fuel Thickness CM Observed Low = <0.5 Calculated Value	Fuel Thickness CM Observed Avg = 13.3 Calculated Value	Fuel Thickness CM Observed High = 38.4 Calculated Value
Porosity = 0.27			
Farr at 20 dynes/cm	Ignore	.5	3.4
Farr at 15	Ignore	.9	4.3
Farr at 10	Ignore	1.5	5.7
AF at 20	Ignore	-1.4	5.4
AF at 15	Ignore	0.0	6.8
AF at 10	Ignore	1.9	8.7
AF at 5	Ignore	4.5	11.3
CONCAWE	Ignore	3.9	11.5
Porosity = 0.35			
Farr at 20	Ignore	.6	3.9
Farr at 15	Ignore	1.1	4.9
Farr at 10	Ignore	1.8	6.7
AF at 20	Ignore	-1.6	7.1
AF at 15	Ignore	.1	8.9
AF at 10	Ignore	2.3	11.1
AF at 5	Ignore	5.4	14.2
Porosity = 0.4			
Farr at 20	Ignore	.7	4.3
Farr at 15	Ignore	1.1	5.3
Farr at 10	Ignore	2.0	7.5
AF at 20	Ignore	-1.8	8.1
AF at 15	Ignore	0.0	10.0
AF at 10	Ignore	2.7	12.7
AF at 5	Ignore	6.0	16.1
Porosity = 0.45			
Farr at 20	Ignore	-.1	2.6
Farr at 15	Ignore	0.1	5.6
Farr at 10	Ignore	2.3	9.9
AF at 20	Ignore	-7.0	3.6
AF at 15	Ignore	-2.0	8.5
AF at 10	Ignore	3.1	14.4
AF at 5	Ignore	10.0	21.0

Figure 35. Langley AFB Site 4, Well 2
Observed vs Calculated Thickness

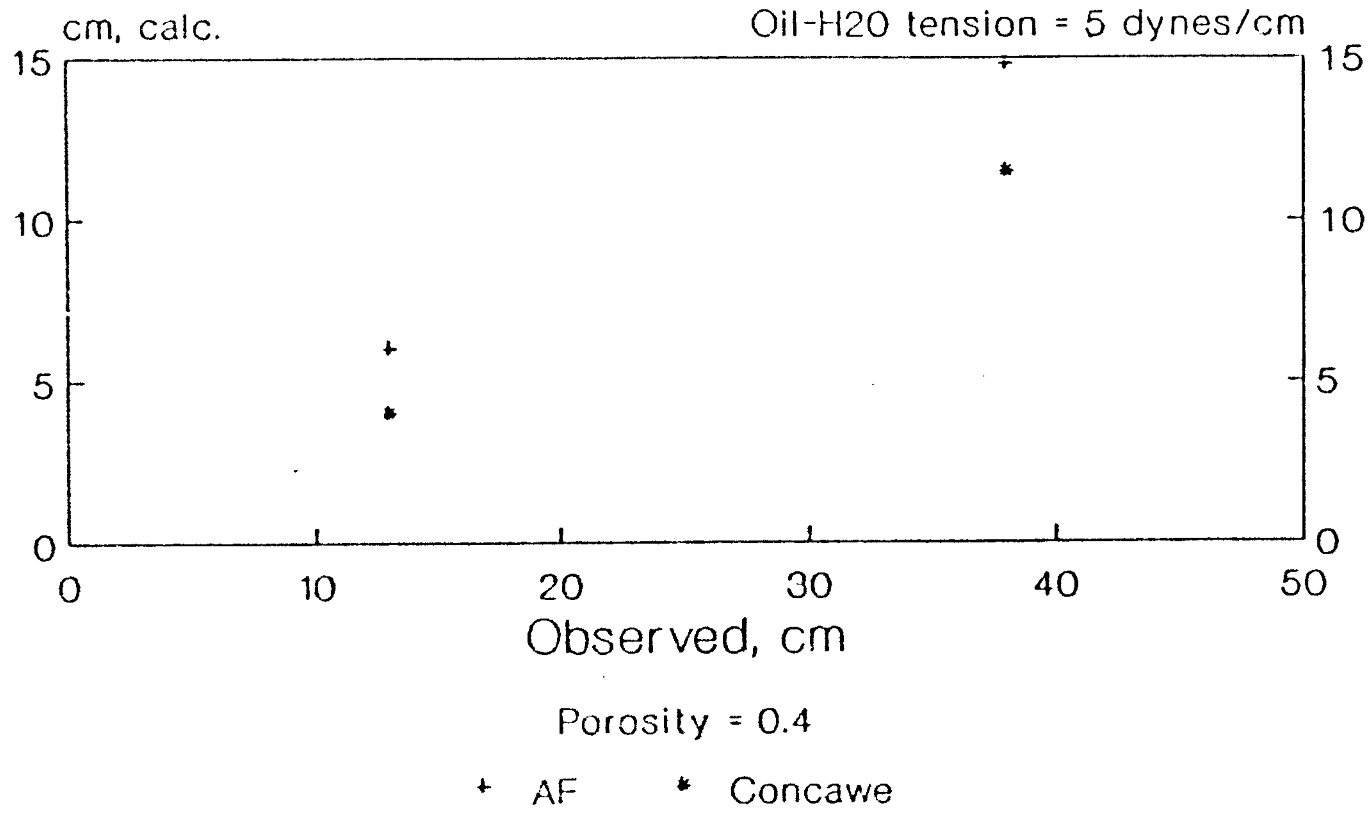


Figure 36. Langley AFB Site 4, Well 2
Observed vs Calculated Thickness

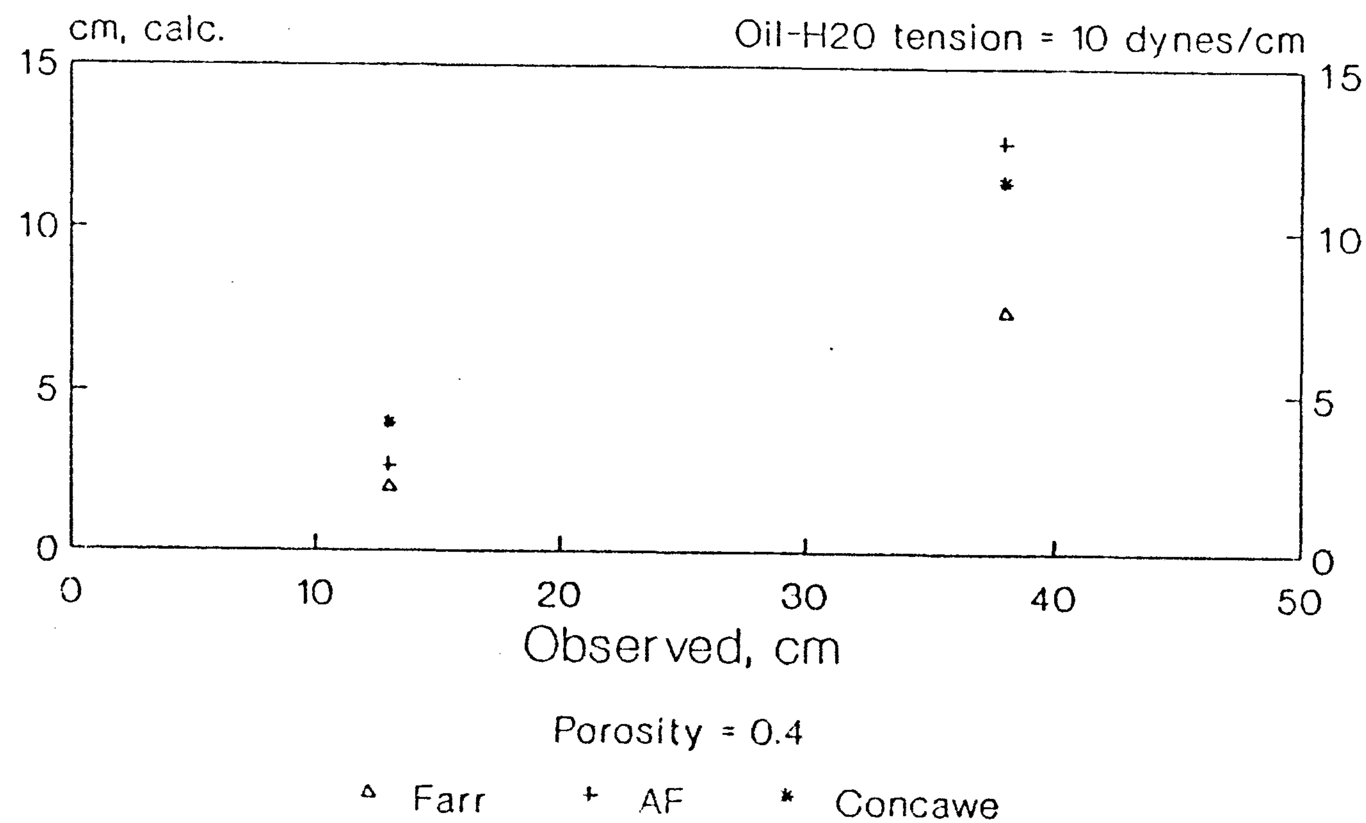


Figure 37. Langley AFB Site 4, Well 2
Observed vs Calculated Thickness

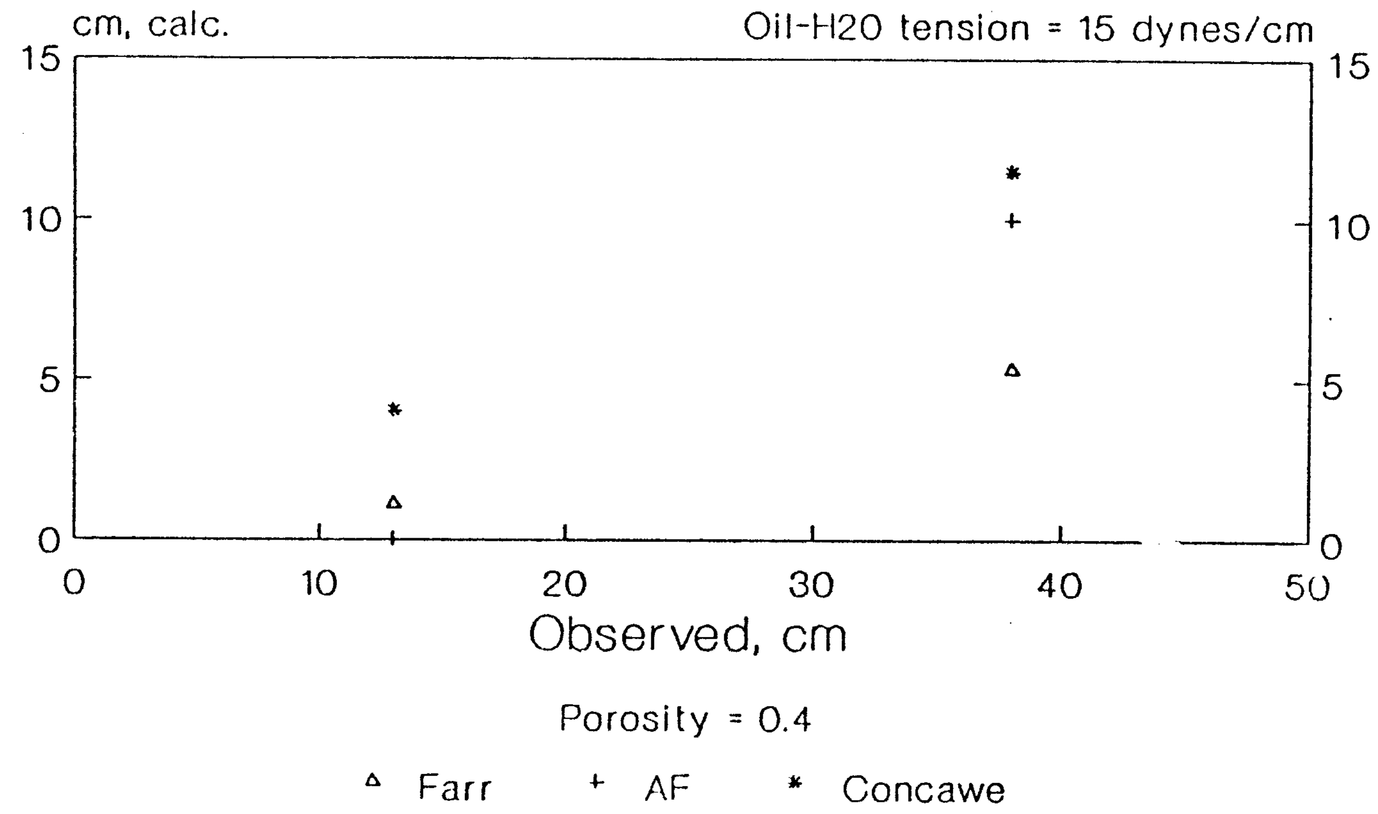


Figure 38. Langley AFB Site 4, Well 2 Observed vs Calculated Thickness

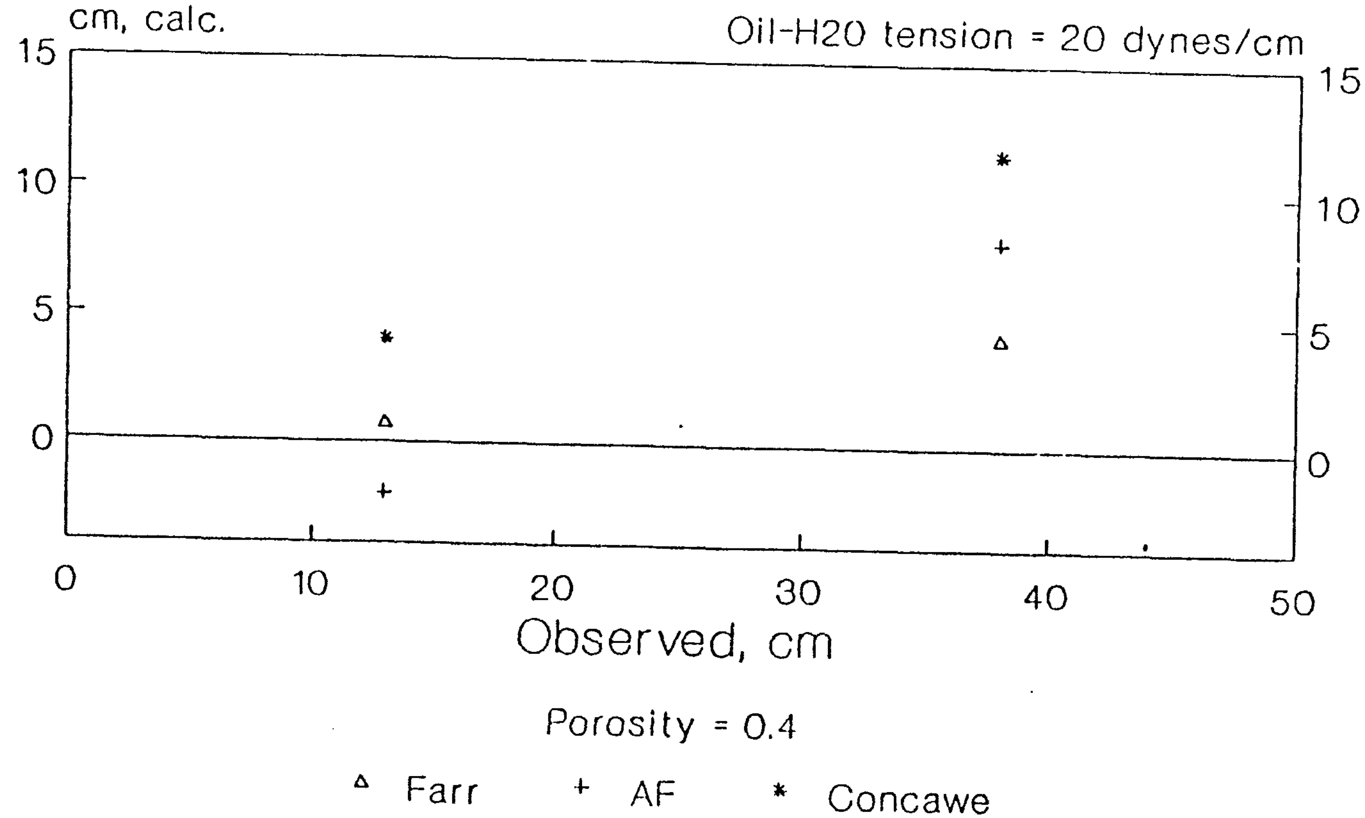
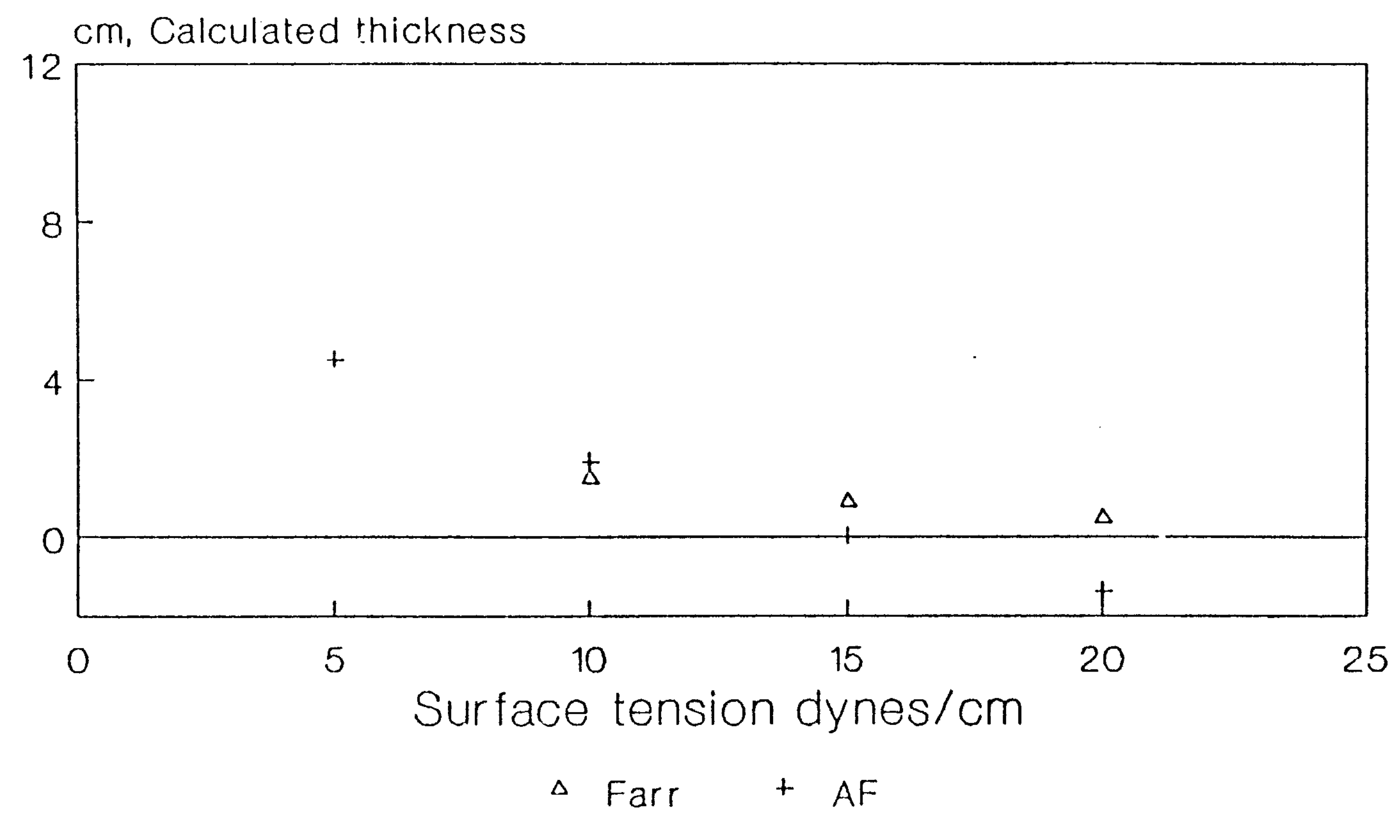
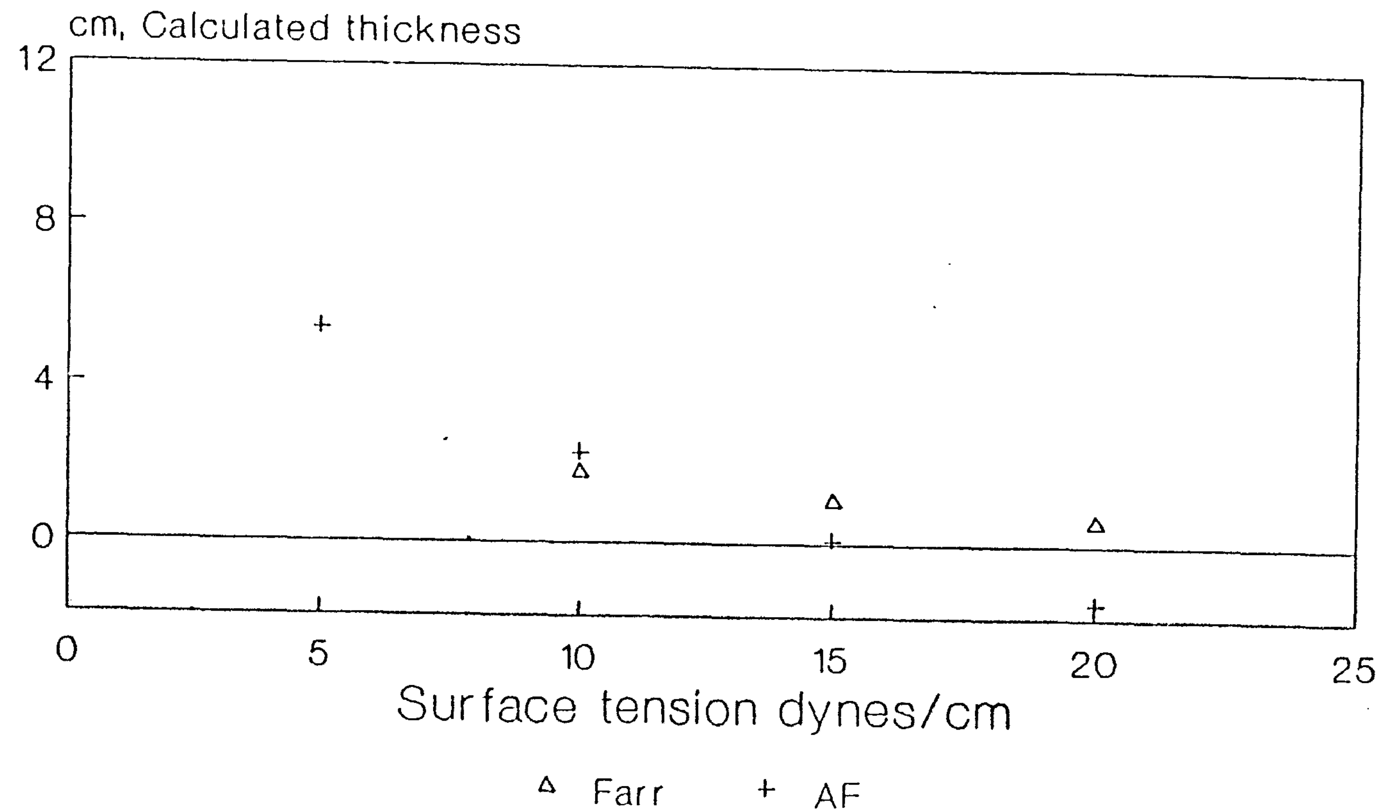


Figure 39. Langley AFB Site 4, Well 2 Impact of Porosity (0.27) on Thickness



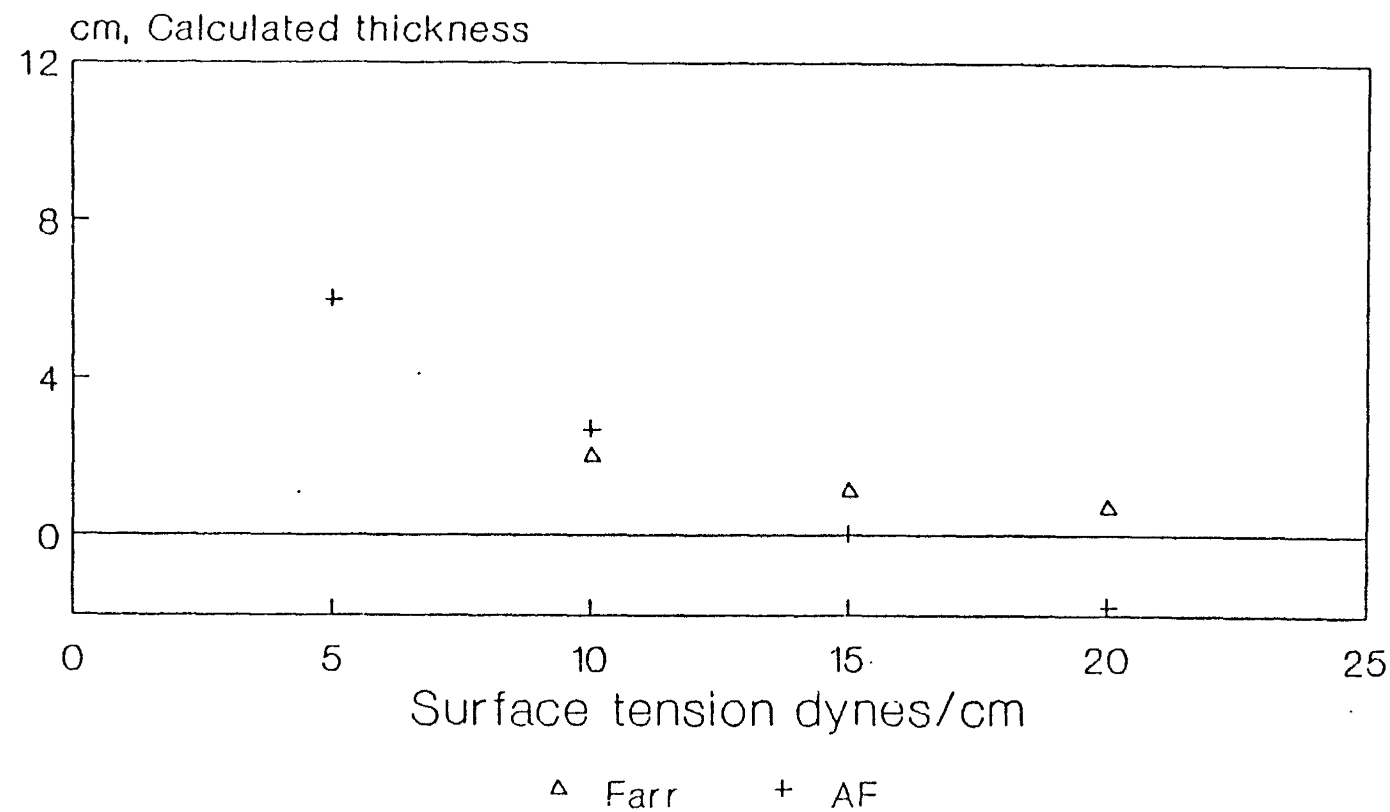
At the avg. observed thickness, 13.3 cm

Figure 40. Langley AFB Site 4, Well 2
Impact of Porosity (0.35) on Thickness



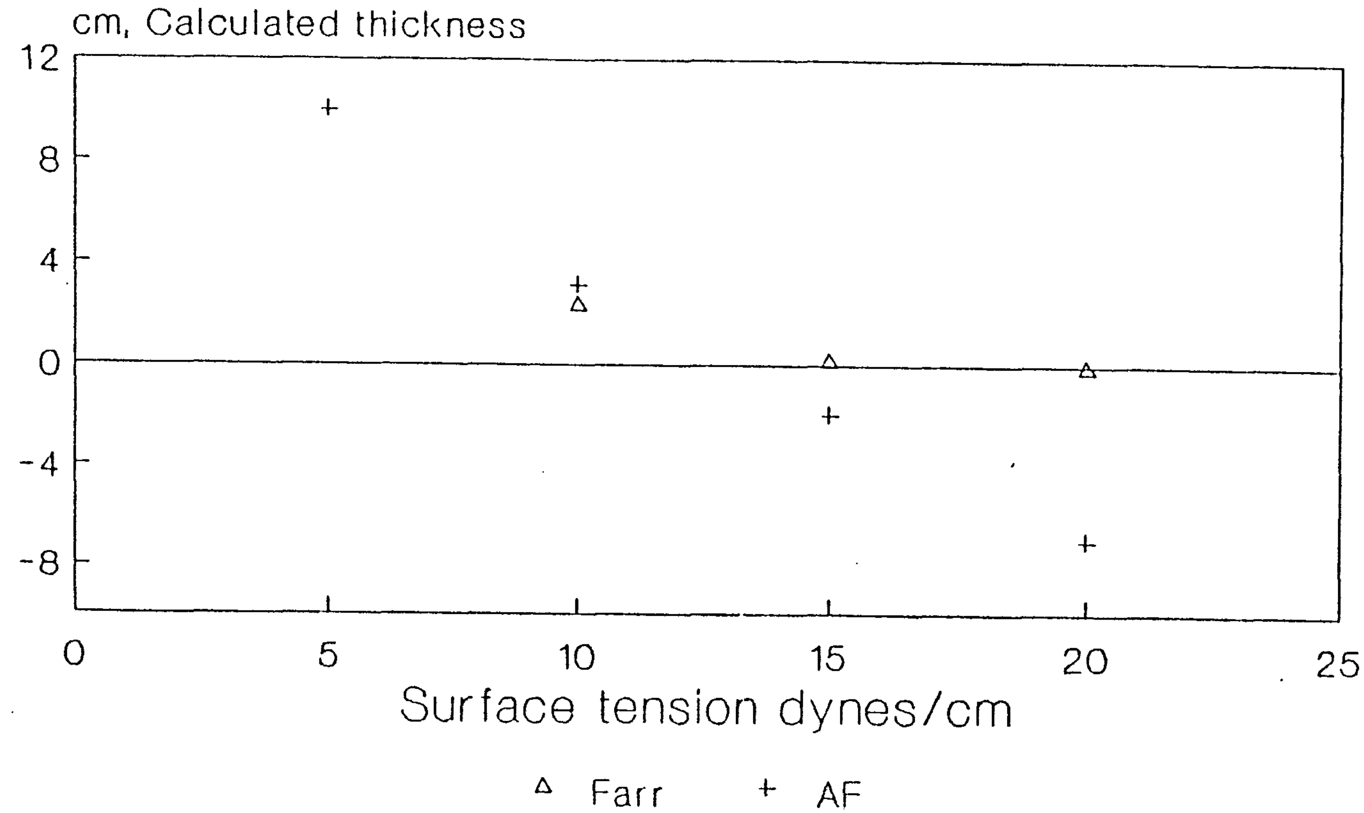
At the avg. observed thickness, 13.3 cm

Figure 41. Langley AFB Site 4, Well 2
Impact of Porosity (0.4) on Thickness



At the avg. observed thickness, 13.3 cm

Figure 42. Langley AFB Site 4, Well 2 Impact of Porosity (0.45) on Thickness



At the avg. observed thickness, 13.3 cm

TABLE 14. OBSERVED VS CALCULATED THICKNESS, LANGLEY WELL 7.

LANGLEY AFB VA Well 7	Fuel Thickness CM Observed Low = 2.1 Calculated Value	Fuel Thickness CM Observed Avg = 15.0 Calculated Value	Fuel Thickness CM Observed High = 33.0 Calculated Value
Porosity = 0.27			
Farr at 20 dynes/cm	-4.0	.7	2.7
Farr at 15	-1.0	1.0	3.5
Farr at 10	0.0	1.8	4.8
AF at 20	-6.0	-1.6	3.1
AF at 15	-3.5	.0	4.9
AF at 10	-1.3	2.0	6.9
AF at 5	.6	5.0	9.9
CONCAWE	.6	4.5	9.8
Porosity = 0.35			
Farr at 20	-2.8	.8	3.2
Farr at 15	-1.7	1.2	4.0
Fatt at 10	-.5	2.1	5.6
AF at 20	-3.0	-1.0	4.2
AF at 15	-2.2	.1	6.4
AF at 10	.0	2.6	8.9
AF at 5	1.7	6.2	12.5
Porosity = 0.4			
Farr at 20	.0	1.0	3.4
Farr at 15	.0	1.4	4.3
Farr at 10	.1	2.3	6.1
AF at 20	-2.4	-.2	5.0
AF at 15	-.5	-.1	7.2
AF at 10	0.0	2.9	10.1
AF at 5	1.7	6.9	14.1
Porosity = 0.45			
Farr at 20	-1.0	-.2	1.9
Farr at 15	.1	.4	4.0
Farr at 10	.3	2.7	8.2
AF at 20	-10.0	-8.0	.1
AF at 15	-1.0	-2.5	5.5
AF at 10	1.2	3.8	11.9
AF at 5	5.0	10.8	18.9

Figure 43. Langley AFB Site 4, Well 7 Observed vs Calculated Thickness

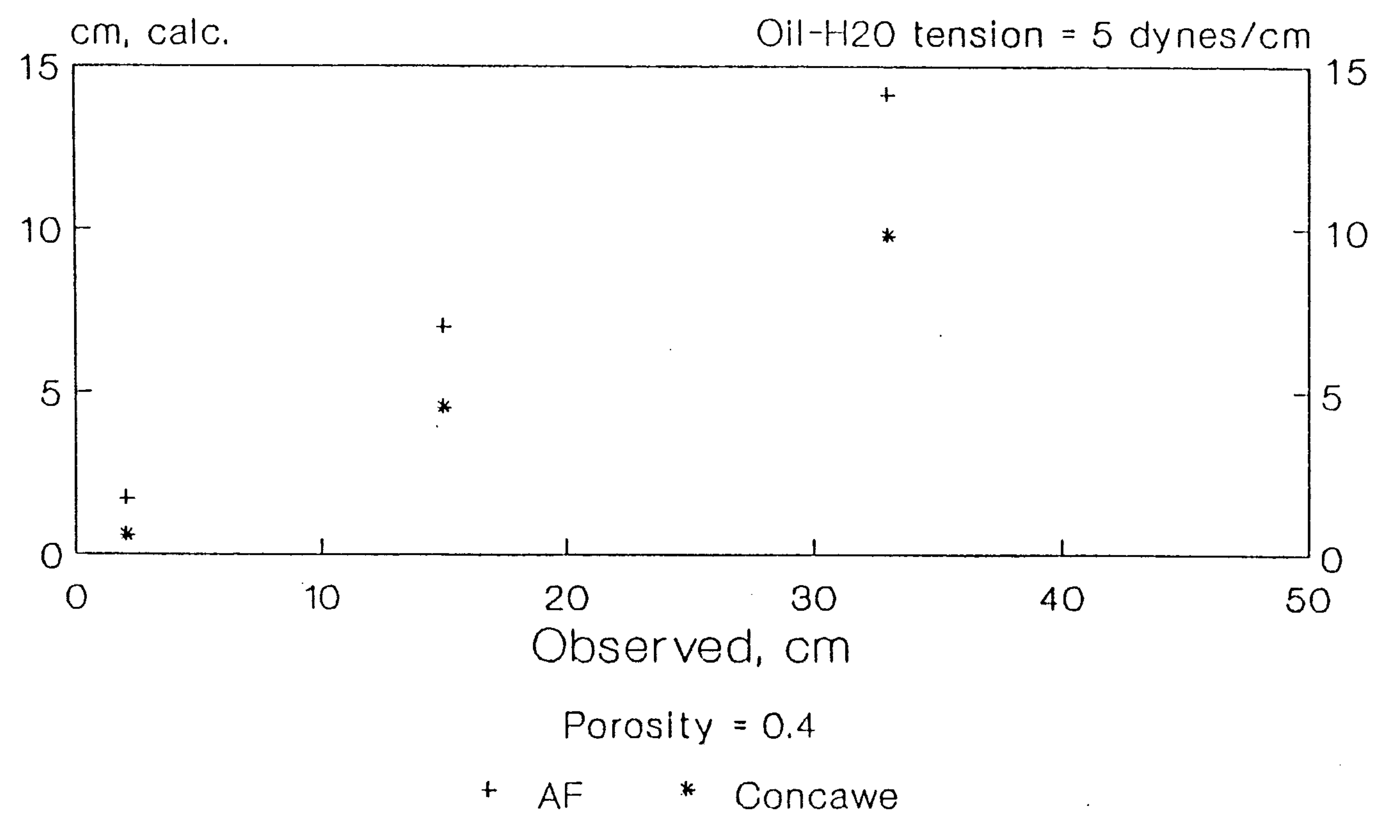


Figure 44. Langley AFB Site 4, Well 7 Observed vs Calculated Thickness

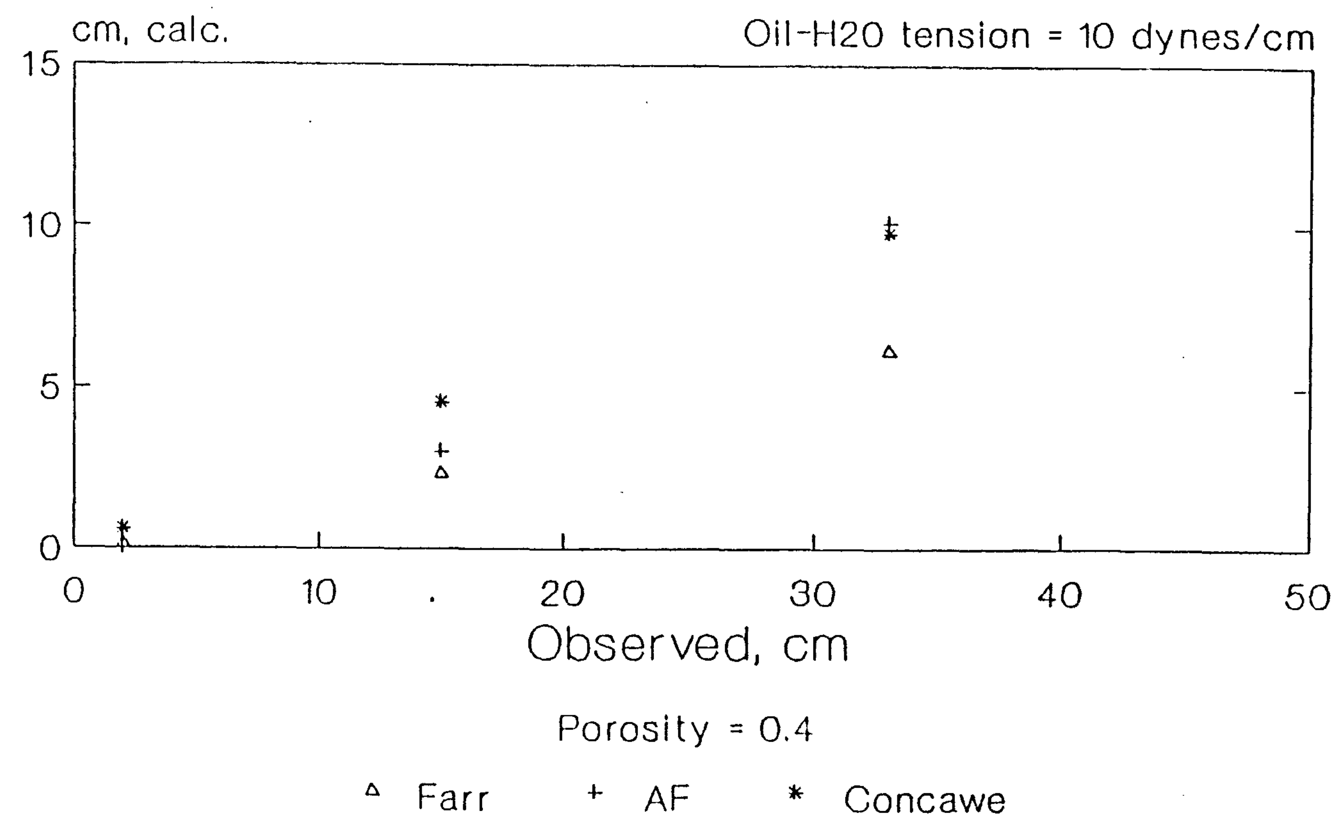


Figure 45. Langley AFB Site 4, Well 7
Observed vs Calculated Thickness

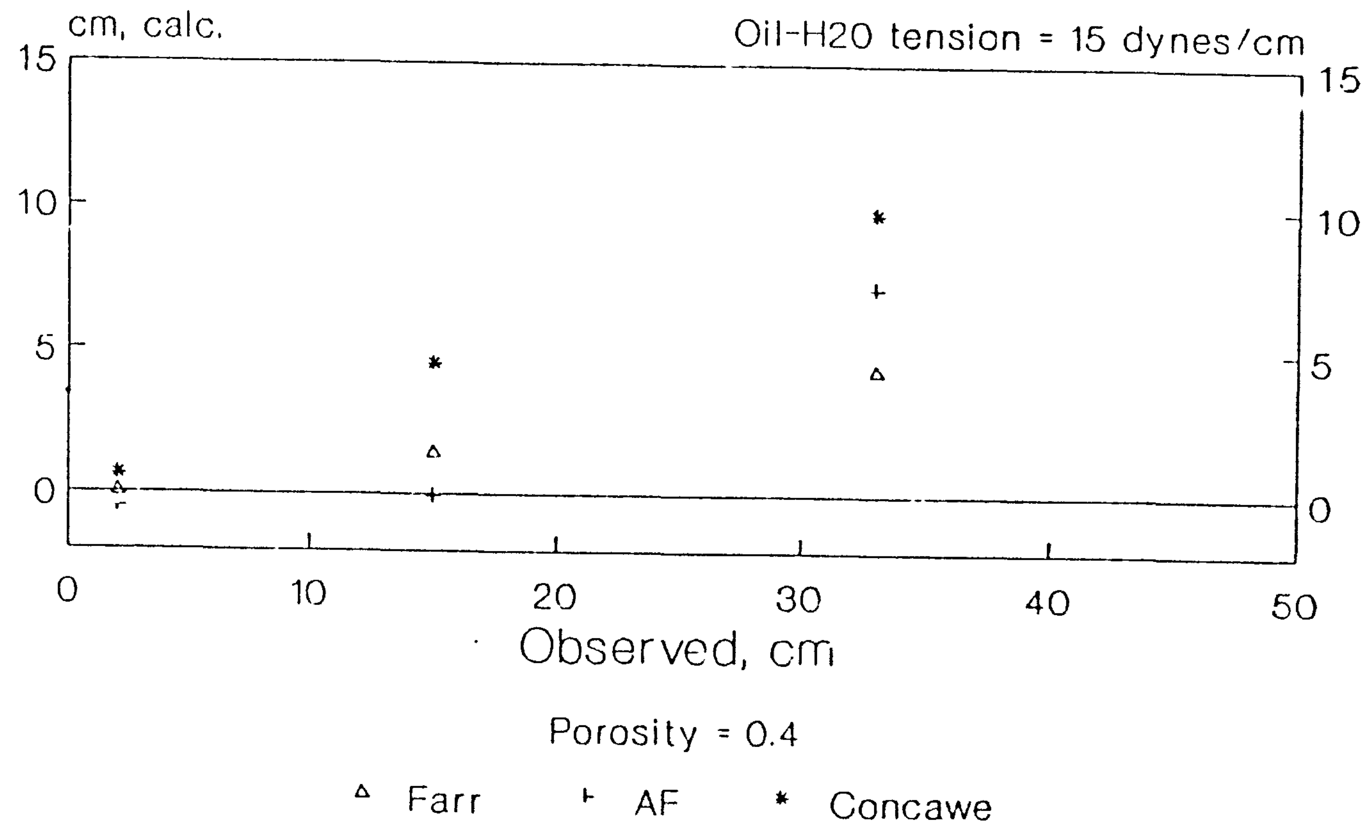


Figure 46. Langley AFB Site 4, Well 7 Observed vs Calculated Thickness

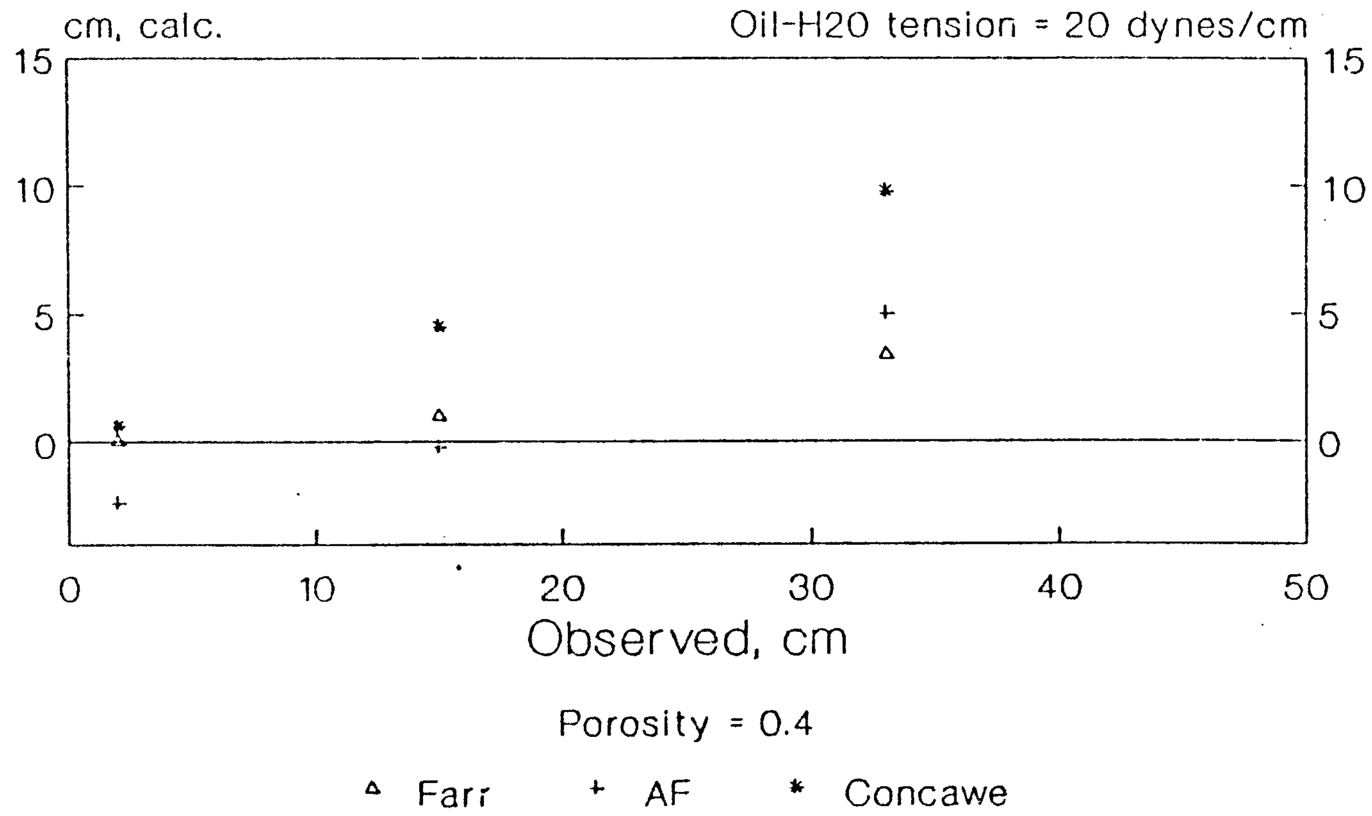
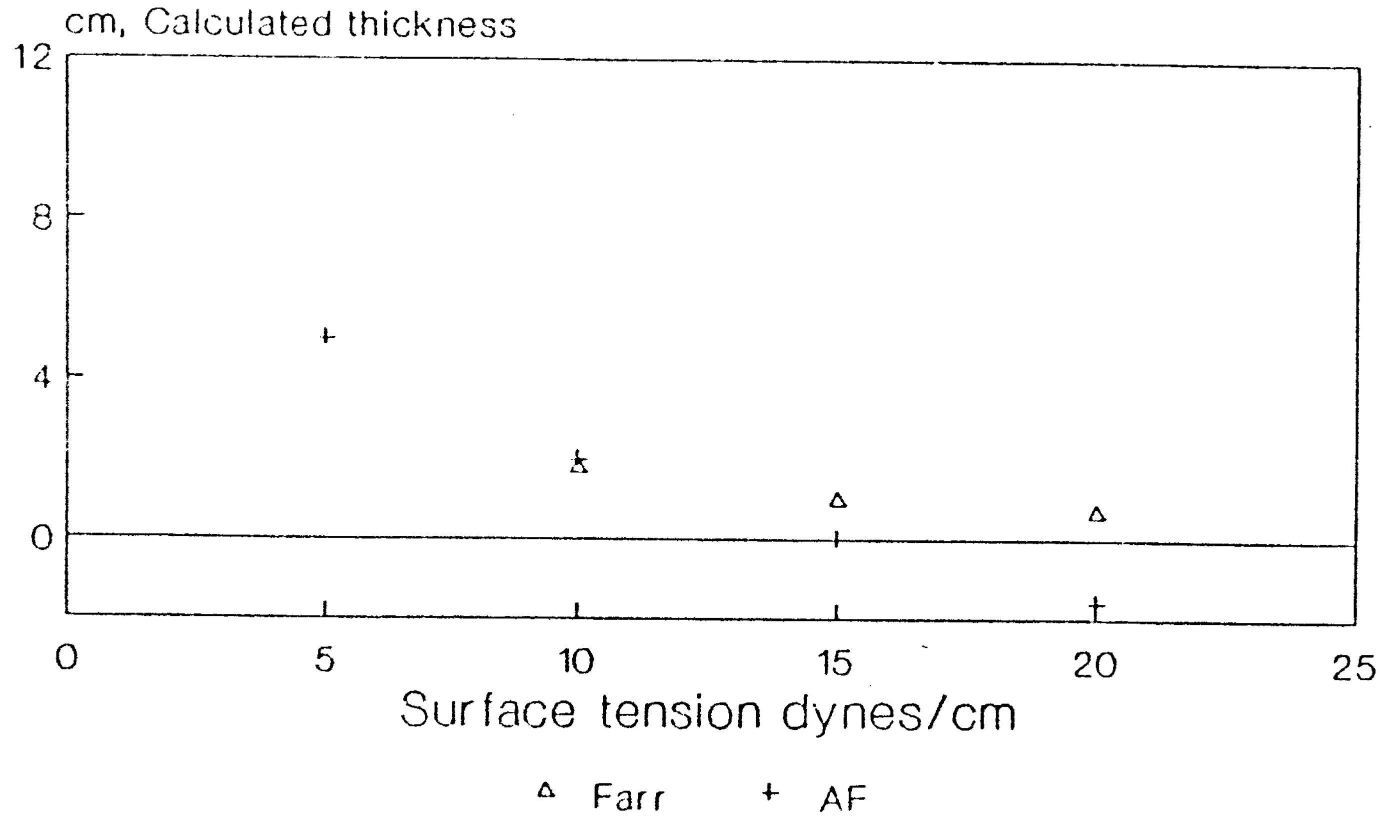
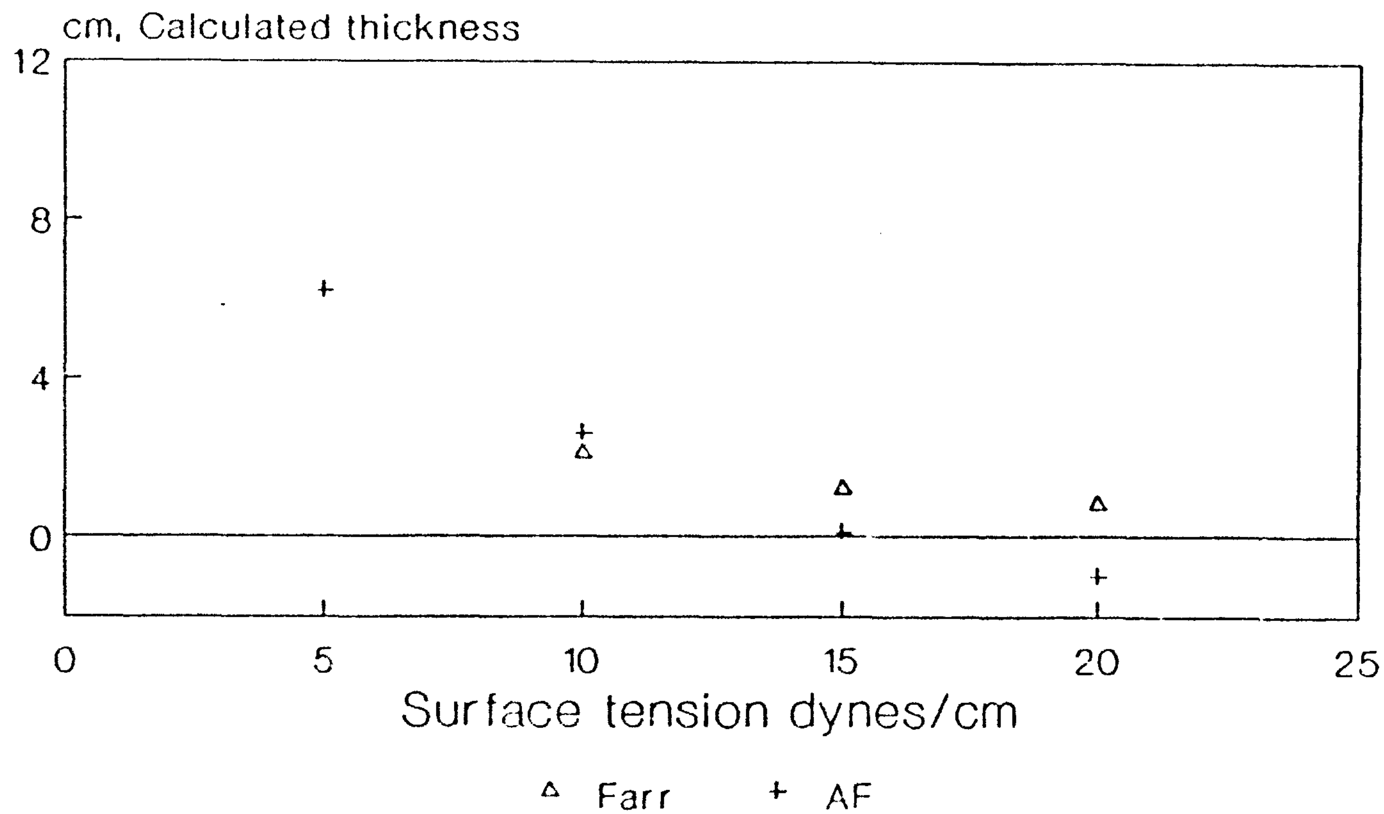


Figure 47. Langley AFB Site 4, Well 7 Impact of Porosity (0.27) on Thickness



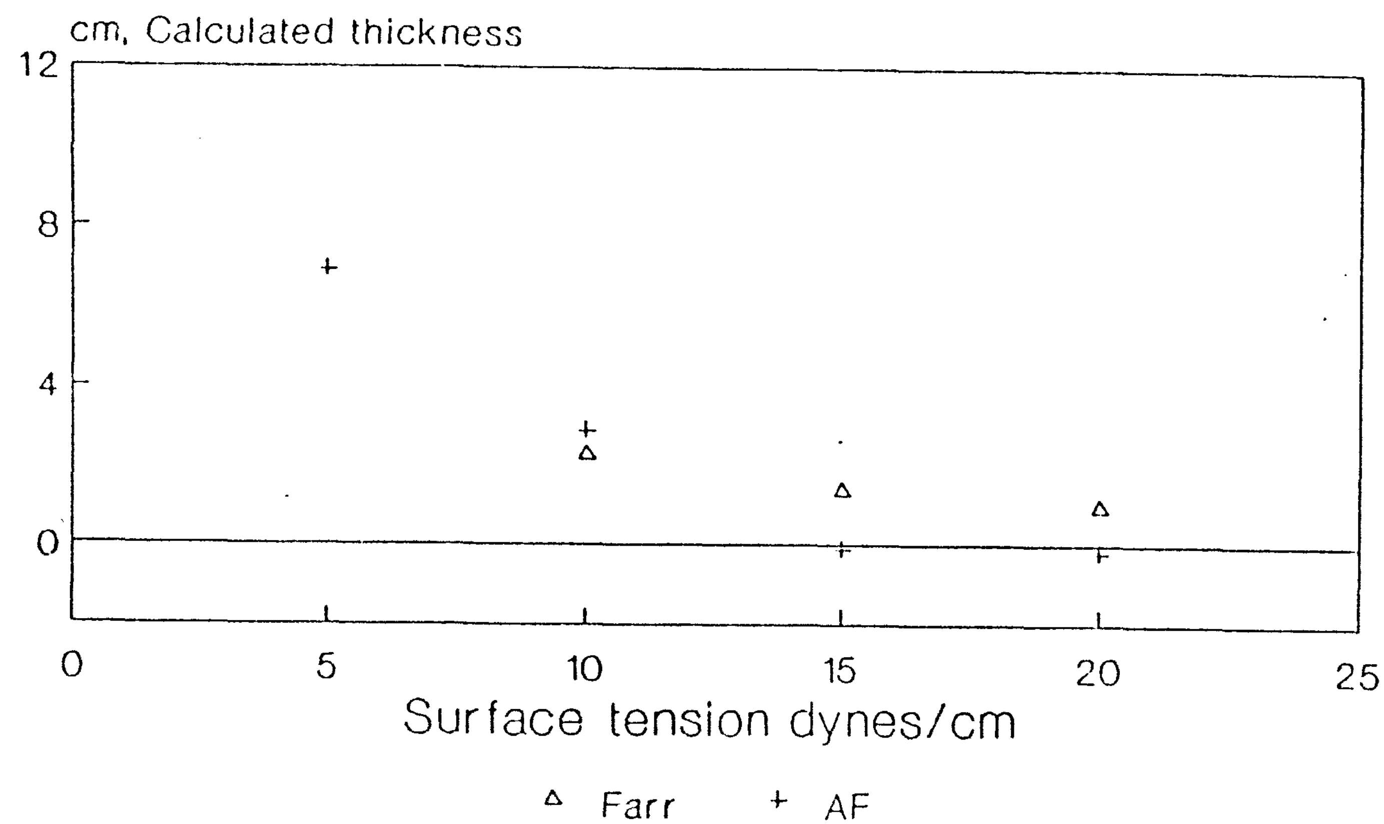
At the avg. observed thickness, 15 cm

Figure 48. Langley AFB Site 4, Well 7
Impact of Porosity (0.35) on Thickness



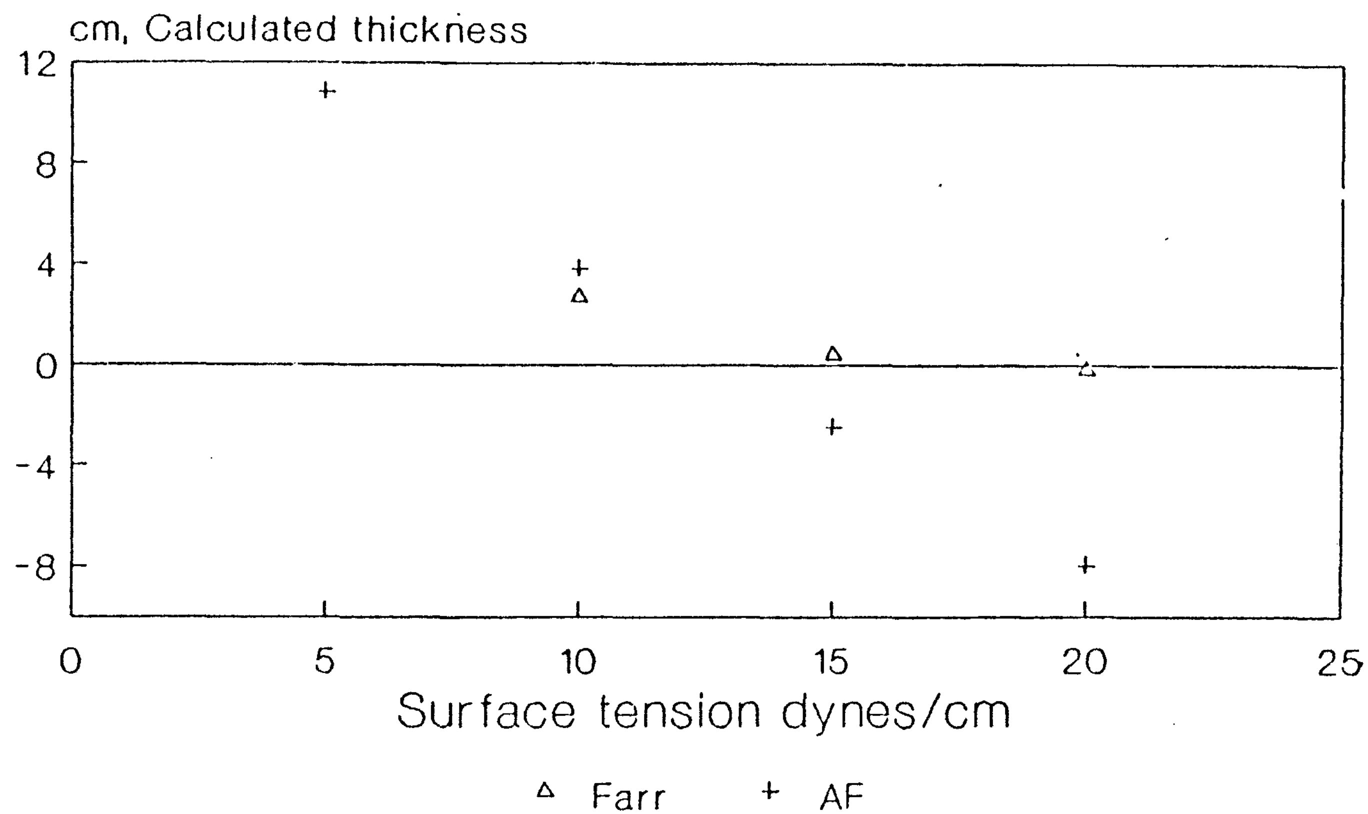
At the avg. observed thickness, 15 cm

Figure 49. Langley AFB Site 4, Well 7
Impact of Porosity (0.4) on Thickness



At the avg. observed thickness, 15 cm

Figure 50. Langley AFB Site 4, Well 7 Impact of Porosity (0.45) on Thickness



At the avg. observed thickness, 15 cm

TABLE 15. OBSERVED VS CALCULATED THICKNESS, LANGLEY WELL 11.

Langley AFB VA Well 11	Fuel Thickness CM Observed Low = 0.3 Calculated Value	Fuel Thickness CM Observed Avg = 5.3 Calculated Value	Fuel Thickness CM Observed High = 17.7 Calculated Value
Prosity = 0.27			
Farr at 20 dynes/cm	Ignore	0.1	3.4
Farr at 15	Ignore	0.3	4.3
Farr at 10	Ignore	0.8	5.7
AF at 20	Ignore	-3.50	4.60
AF at 15	Ignore	-1.80	6.40
AF at 10	Ignore	.20	8.40
AF at 5	0.50	3.10	11.30
CONCAWE	0.40	2.40	11.50
Porosity = 0.35			
Farr at 20	Ignore	.20	3.90
Farr at 15	Ignore	.50	4.90
Farr at 10	Ignore	.90	6.70
AF at 20	Ignore	-4.00	6.10
AF at 15	Ignore	-2.00	8.30
AF at 10	Ignore	.20	10.80
AF at 5	.70	3.70	14.40
Porosity = 0.4			
Farr at 20	-2.00	.20	4.30
Farr at 15	-.30	.50	5.30
Farr at 10	.05	1.00	7.50
AF at 20	-6.00	-5.00	7.20
AF at 15	-4.00	-2.80	9.30
AF at 10	-.30	.10	12.30
AF at 5	1.30	4.10	16.20
Porosity = 0.45			
Farr at 20	-1.30	-.40	2.60
Farr at 15	-.01	-.30	5.60
Farr at 10	0.00	.90	9.90
AF at 20	-4.00	-11.00	2.50
AF at 15	-2.50	-6.00	7.90
AF at 10	1.20	.60	14.30
AF at 5	4.60	7.70	21.40

Figure 51. Langley AFB Site 4, Well 11 Observed vs Calculated Thickness

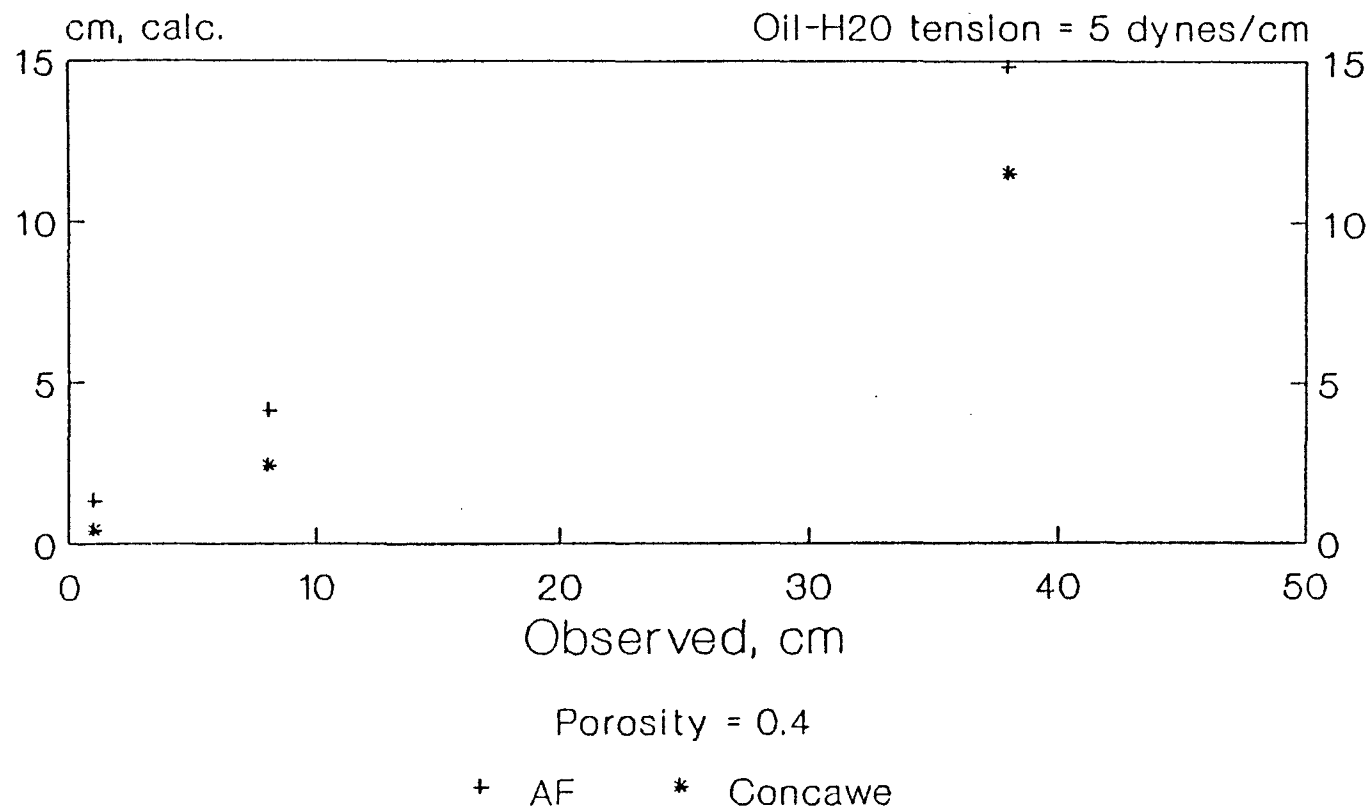


Figure 52. Langley AFB Site 4, Well 11
Observed vs Calculated Thickness

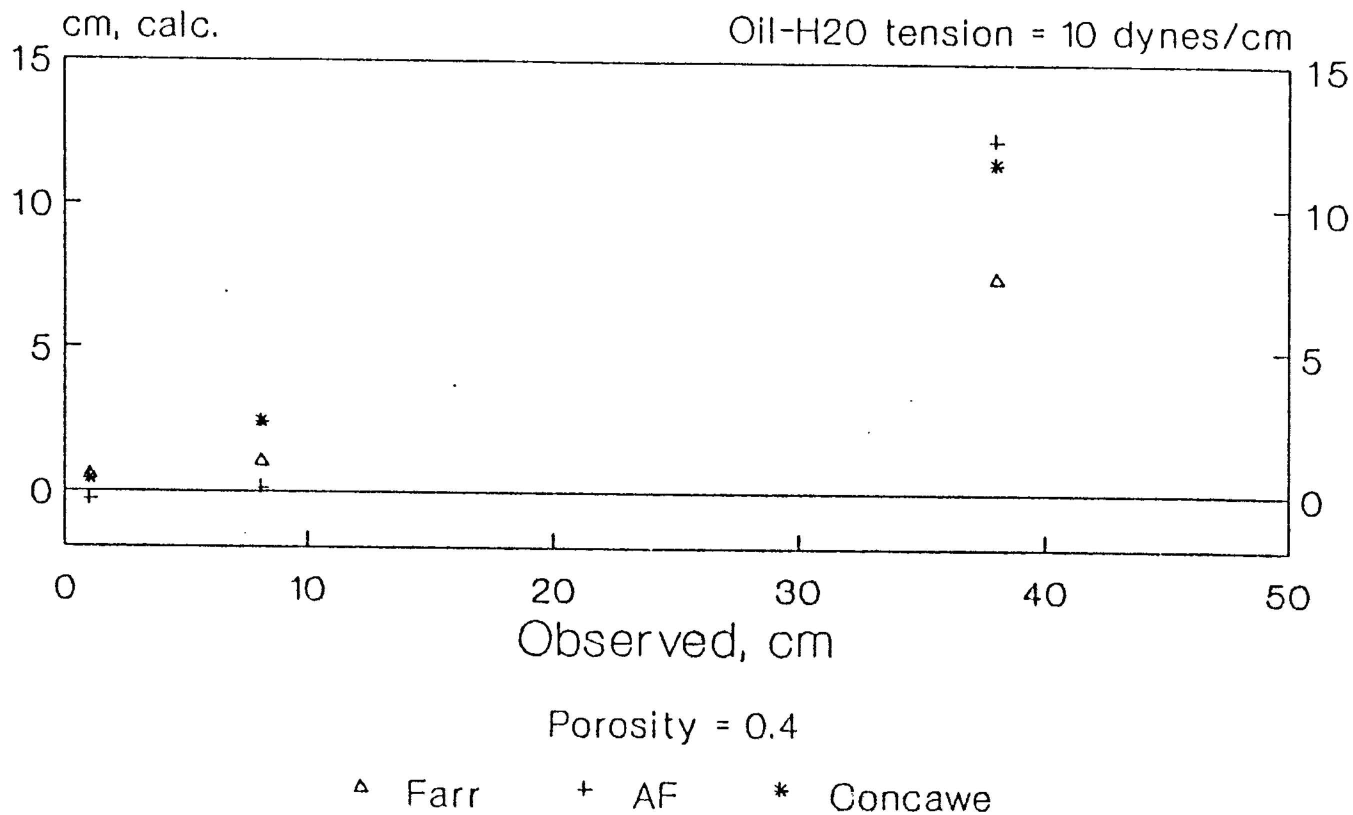


Figure 53. Langley AFB Site 4, Well 11
Observed vs Calculated Thickness

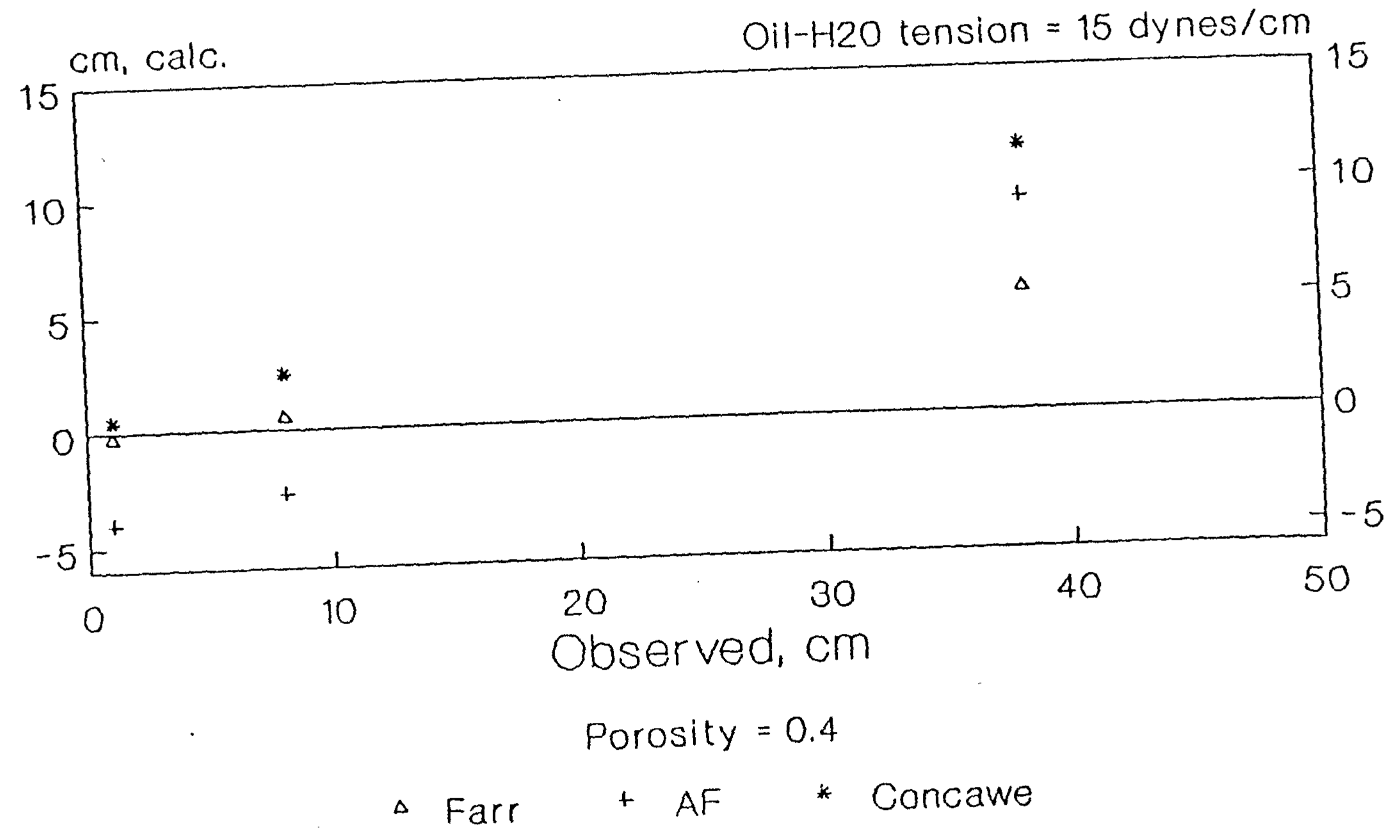


Figure 54. Langley AFB Site 4, Well 11
Observed vs Calculated Thickness

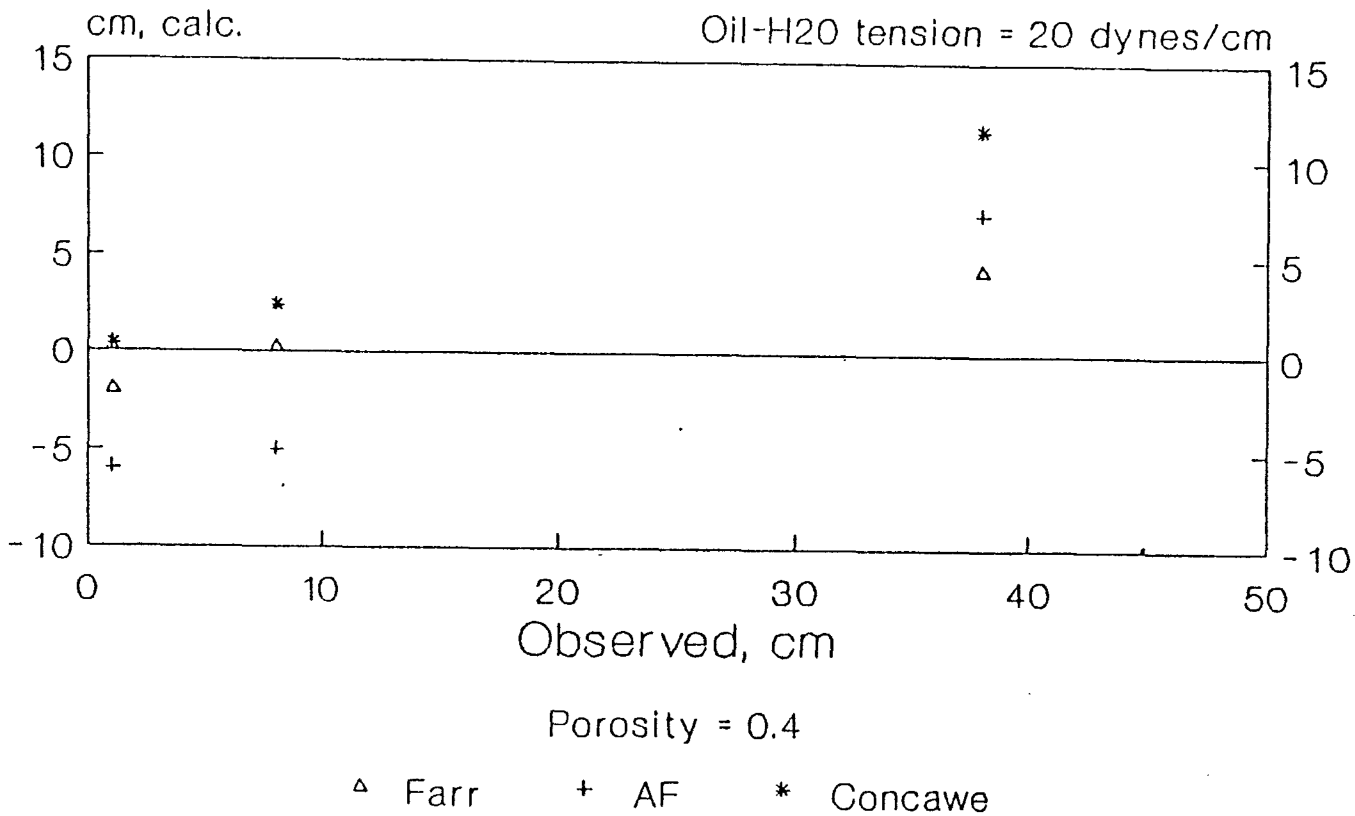
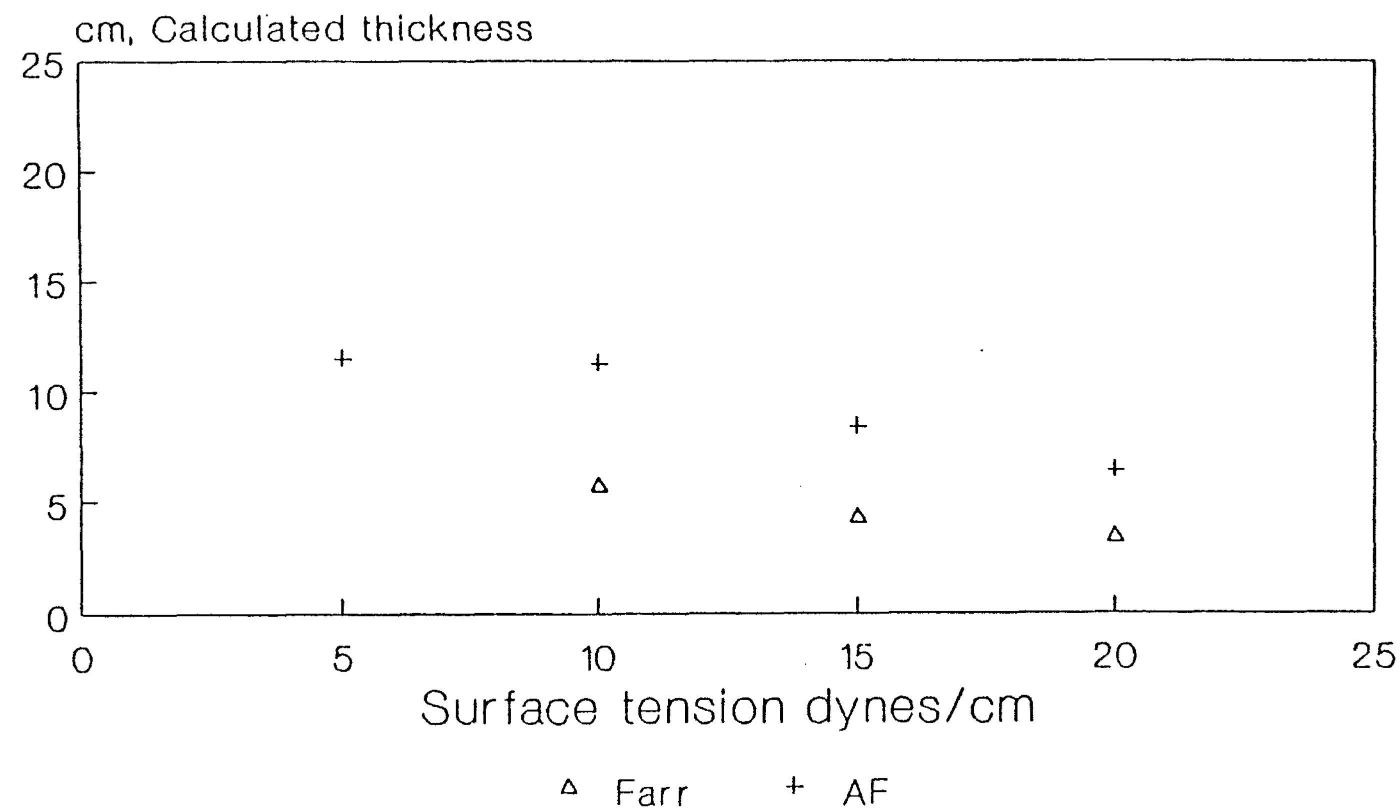
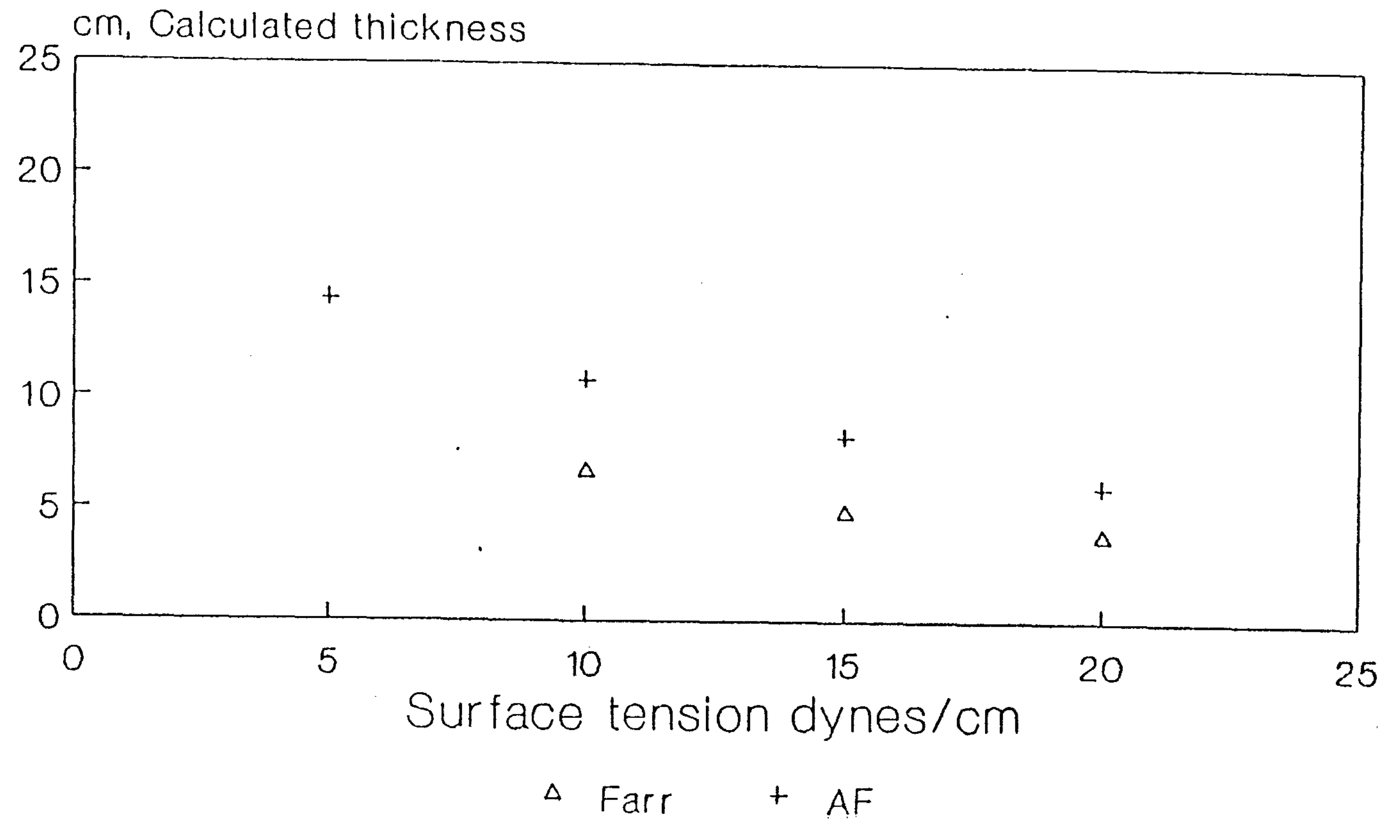


Figure 55. Langley AFB Site 4, Well 11
Impact of Porosity (0.27) on Thickness



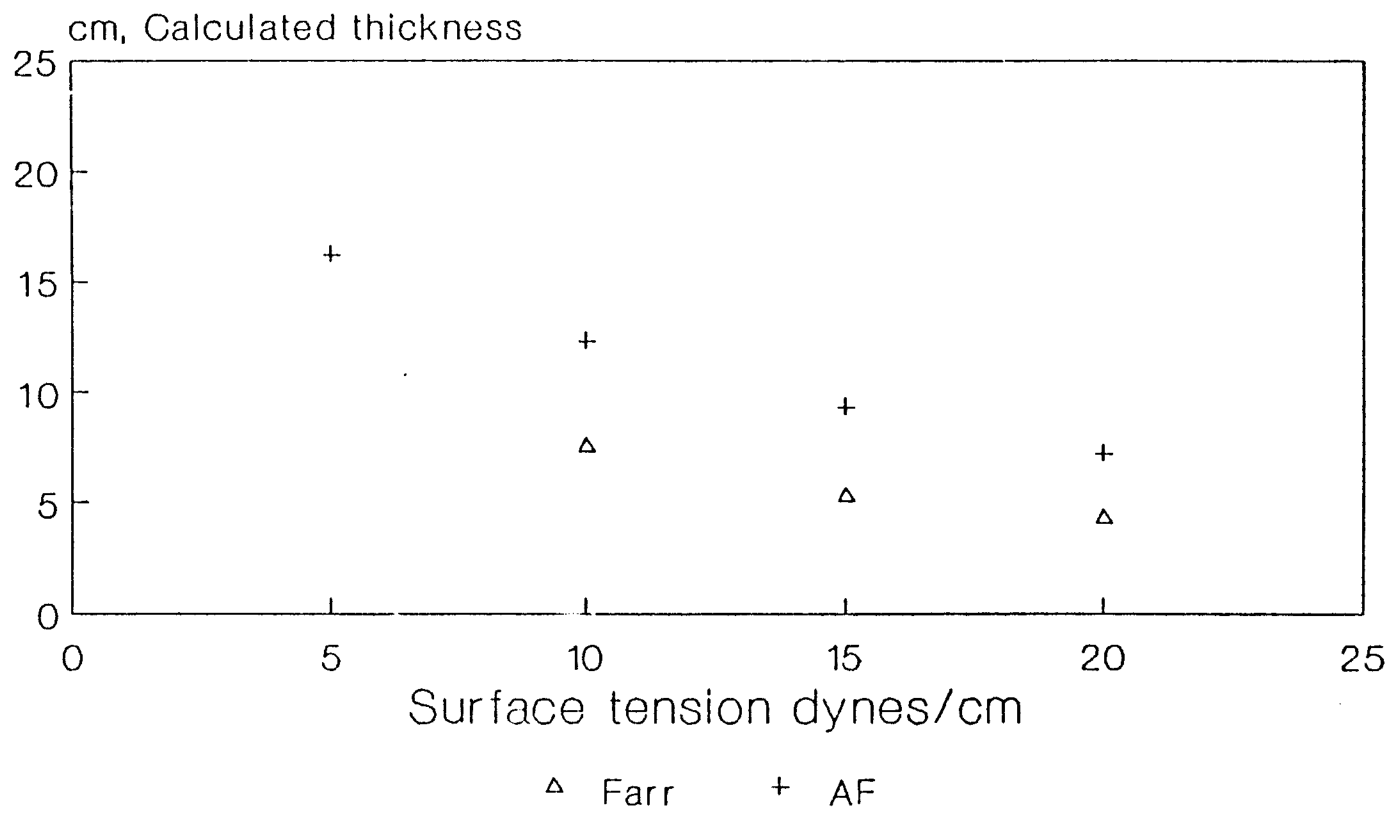
At the high observed thickness, 38.4 cm

Figure 56. Langley AFB Site 4, Well 11 Impact of Porosity (0.35) on Thickness



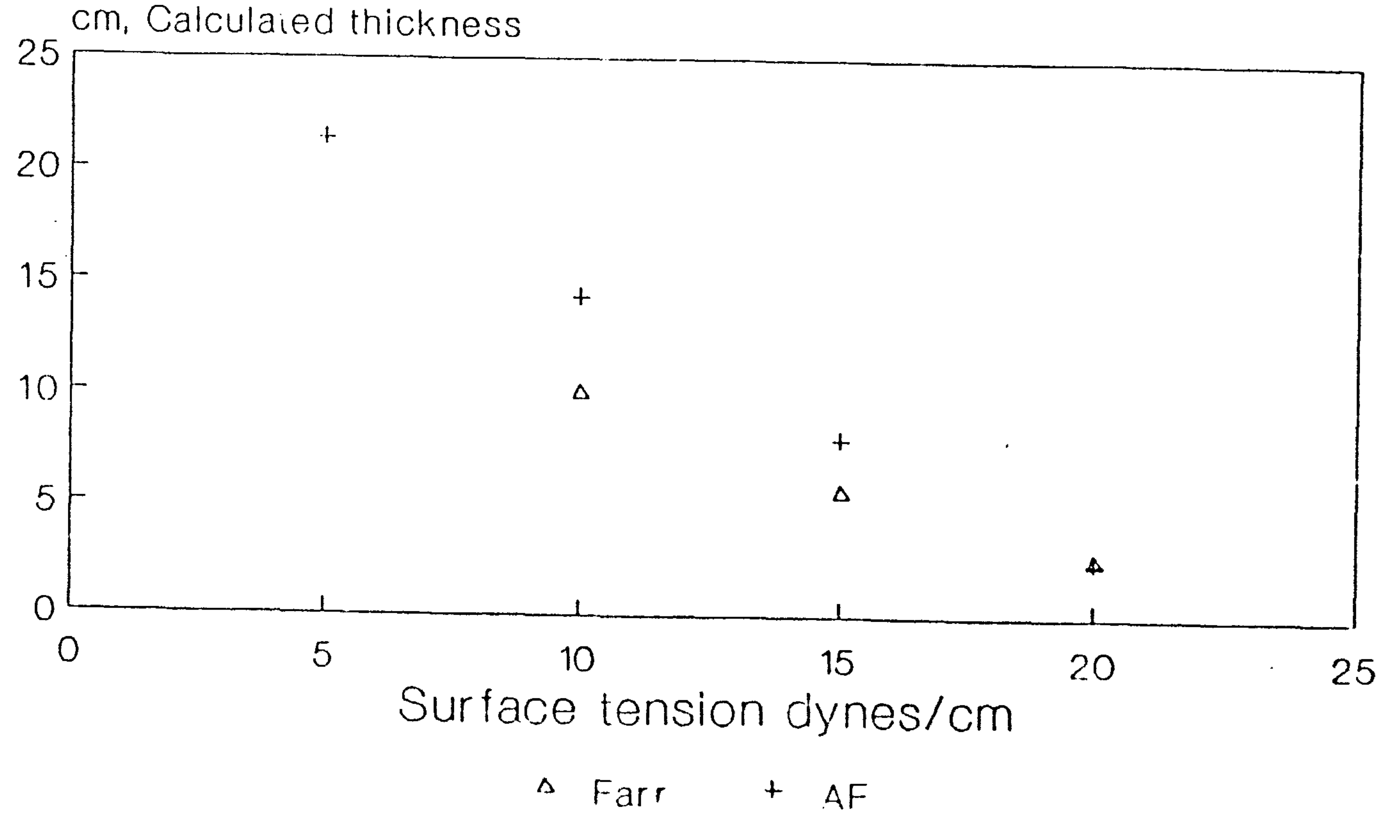
At the high observed thickness, 38.4 cm

Figure 57. Langley AFB Site 4, Well 11
Impact of Porosity (0.4) on Thickness



At the high observed thickness, 38.4 cm

Figure 58. Langley AFB Site 4, Well 11
Impact of Porosity (0.45) on Thickness

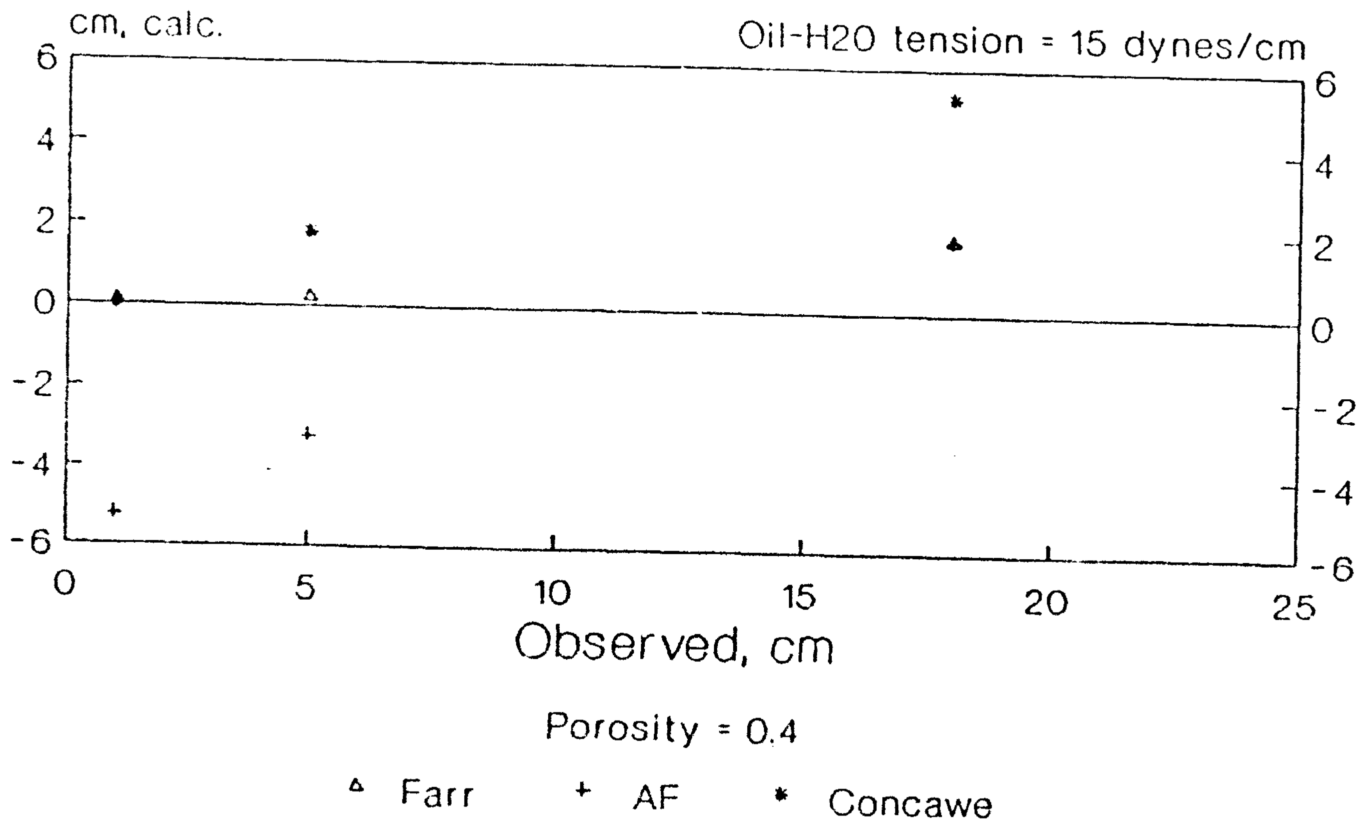


At the high observed thickness, 38.4 cm

TABLE 16. OBSERVED VS CALCULATED THICKNESS, LANGLEY WELL 13.

Langley AFB VA Well 13	Fuel Thickness CM Observed Low = 0.3 Calculated Value	Fuel Thickness CM Observed Avg = 5.3 Calculated Value	Fuel Thickness CM Observed High = 17.7 Calculated Value
Porosity = 0.4			
Farr at 15 dynes/cm	0.1	0.2	1.8
AF at 15	-5.2	-3.2	1.8
Concave	0.0	1.6	5.3

Figure 59. Langley AFB Site 4, Well 13 Observed vs Calculated Thickness



WILLIAMS AFB AZ

SITE HISTORY

Base personnel discovered the presence of a floating layer of JP-4 in March 1987 during a Phase II Installation Restoration Program (IRP) investigation. The source of the JP-4 was leaking underground storage tanks and fuel transport lines in the liquid fuels storage area (LFSA). The site is known as IRP site LFSA. The IRP contractor estimates the fuel volume at this location to range from 750,000 to 1,000,000 gallons. The area of contamination is thought to cover several acres, however a definite zone of contamination has yet to be defined. Twenty-four monitoring wells have been installed at the LFSA site, however only the following five wells have consistently shown free product: Well LI-06, W-01, W-05, W-09 and W-13. The free product appears consistently at a depth of approximately 230 feet. During a pilot scale test in 1989, five thousand gallons of free product was recovered. No other active remediation efforts were underway during the period of this study. The IRP contractor estimates site restoration (free-fuel recovery only) at this location could last five to six years. (1989 Williams AFB IRP report).

GEOLOGY

The unsaturated zone at the LFSA is quite variable over the 200 plus feet to the water table. Generally, it is coarse grained sand, some silty clay, and clayey silty sand grading to coarse grained sand and gravel. The zone of interest, that is the fuel water interfacial zone (saturated) is characterized quite differently by the two well logs available for this site. One geologist in 1986 characterized the saturated zone of well LI-06 to be very coarse-grained sand and gravel with no clay present (see well log LI-06, Appendix 4, WILLIAMS). In 1989, a different contractor rendered a very different description of the saturated zone of well W-01, located only 100 feet from well LI-06. (see well log W-01, WILLIAMS Appendix). The difference between the two well logs (amount of fines present) presented a problem to this researcher in that the SOILPROP inputs differed greatly by the interpreted particle size. Also, the two stated well logs were the only ones available for this location. No particle size distributions were available for review. The SOILPROP input for LI-06 was: 25% medium sand, 50% coarse sand, and 25% fine gravel. The SOILPROP input for well W-01 was: 40% fines, 50% fine sand and 10% medium sand.

OBSERVED JP-4 LEVELS

Contractor and AF Civil Engineering personnel took monthly readings of the JP-4 thickness level and depth to water table for the eighteen months of this study. The WILLIAMS appendix contains tables of the observed values. The differences in the JP-4 thickness observed was very large compared to very small changes in the depth to water table. All five of the wells that had JP-4 appear in them are within a 1000 foot diameter zone using well W-01 as center. The lowest value of JP-4 found at the LFSA site was 30 cm in well W-05 (19 October, 1989); the highest level recorded was 448 cm in well W-01 (12 September 1989), which is fifteen times the lowest value. The average thickness of JP-4 at the LFSA site was calculated to be 260 cm from data collected from five wells. The range in the average thickness of JP-4 between the five wells was 186 cm, which indicates the fuel was not in good equilibrium with the water table. The variation of fuel level within each well was great in three of the wells, and relatively small in two wells.

The difference in observed fuel levels within each well is shown in the table below:

TABLE 17. DIFFERENCES IN OBSERVED FUEL THICKNESSES - WILLIAMS

Well	low (cm)	high (cm)	Difference (cm)
LI-06	179	360	181
W-01	294	448	154
W-05	30	426	396
W-09	32	338	306
W-13	34	259	225

COMPUTED JP-4 LEVELS

Using the well logs as a particle size source for this area, SOILPROP produced an air-water capillary (Pd^{aw}) head of 0.867 cm at porosity of 0.4 and oil-water surface tension (σ_{ow}) of 15 dynes/cm for well LI-06.

The SOILPROP output for well W-01 was 9.35 cm at the same parameters. Due to the great difference in the two values, and the fact the wells are only 100 feet apart from each other, both SOILPROP outputs were used for each calculated JP-4 thickness.

This was done to show the great difference in calculated answers based on the inputs available. Results are shown on tables 18 and 19.

Figures 60-69 illustrate the values shown on tables 18 and 19. Some of the answers generated using the AF equation at this location were negative; these values are shown as zero on the appropriate figure.

As expected, the Concawe equation shows a linear relationship between the observed and calculated values. The Concawe answers also compare much better to the Farr and AF equations when using the well LI-06 Pd^{aw} data.

The unique feature of this set of calculations is the large differences between the calculated answers using the same equations, same observed thickness, and only changing the Pd^{aw} value of the Farr and AF equations.

SITE CONCLUSIONS

GEOLOGY

The calculated volume of JP-4 fuel present at any site is highly dependent on accurate geologic information being furnished when using the Farr and AF equations. Correct geologic information is not as important when using the Concawe equation, as many of the factors (porosity, surface tension) are not used in the basic equation. The importance

of having the correct particle size distribution available is preeminent as the average thickness of JP-4 calculated at this site is larger from 52 to 77 cm over lower values when using a Pd^{aw} of 0.76 cm rather than 9.35 cm (difference in amount of fines).

The Williams calculated thicknesses should be classified as having low degrees of reliability as no particle size distribution was available for SOILPROP input. In addition, only two of five well logs were available for interpretation, and they differed considerably over a relatively small area.

MULTIPLE MEASUREMENTS

The importance of taking multiple fuel level measurements over time of any floating layer is highly meaningful. Due to the wide variations observed from low to high levels of JP-4 seen at this site, the calculated JP-4 thicknesses ranged from 1.2 to 166 cm. Relying on one or two measurements to calculate the volume of JP-4 present can lead to estimations off by a factor of over fifteen using the AF and Farr equations, and a factor of thirteen using Concawe. It can generally be stated that using fewer measurements to base the calculated thickness value, the greater the possibility or margin of error will be.

CALCULATED JP-4 THICKNESS

At this location, the Concawe equation may be the best estimator of the actual thickness of JP-4 on the aquifer. This is due to the uncertainty attached to the AF and Farr equation parameters of porosity, oil-water interfacial tension, and particle size distribution data. The Concawe answer was generally in the mid range of the average AF and Farr answers based on the SOILPROP generated Pd^{aw} values for wells LI-06 and well W-01.

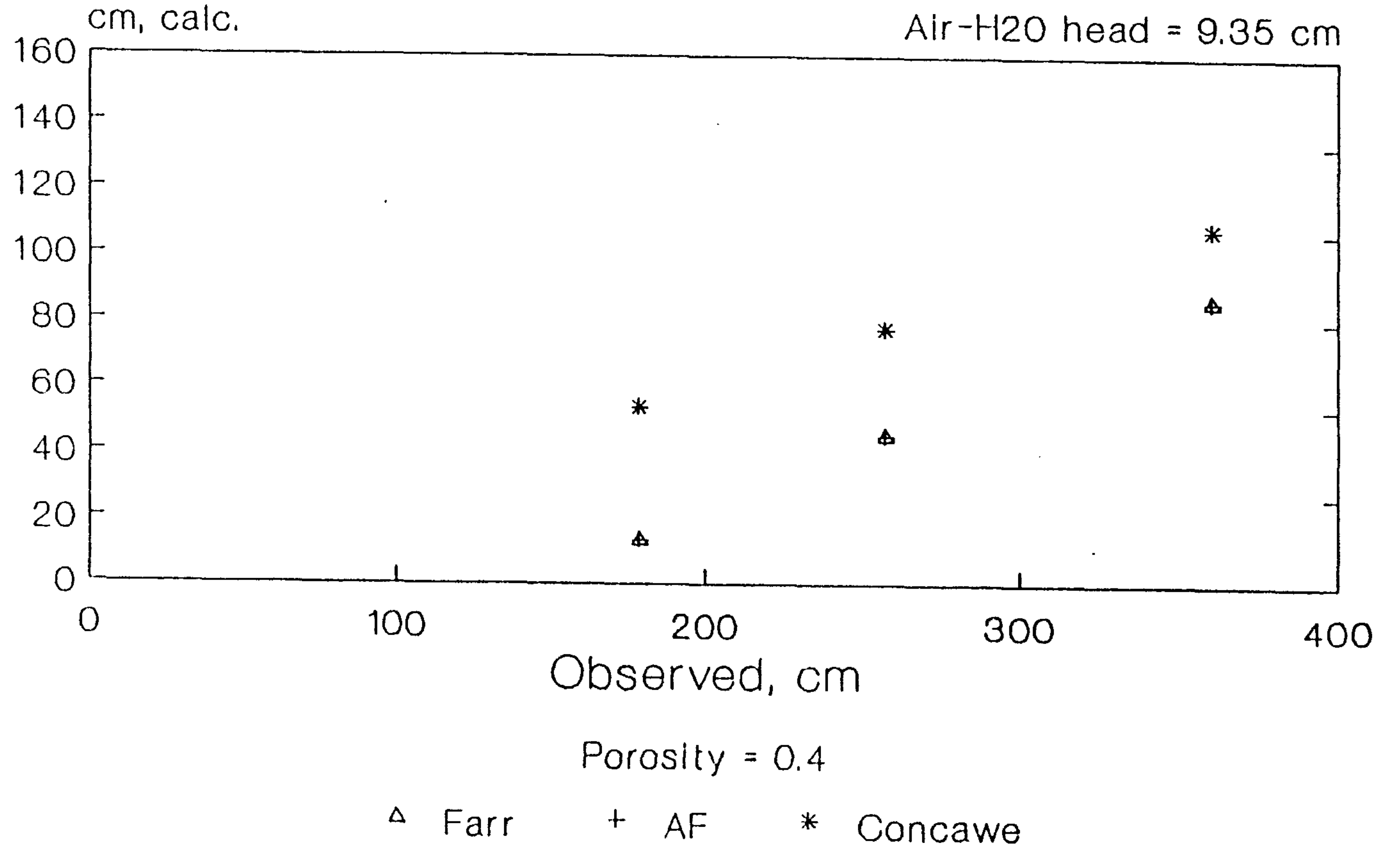
TABLE 18. OBSERVED VS CALCULATED THICKNESS, WILLIAMS WELLS LI-06, W-01, & W-05 AT AIR-H_2O CAPILLARY HEADS OF 0.867 & 9.35 CM.

WILLIAMS AFB AZ Well LI-06	Fuel Thickness CM Observed low = 179 Calculated Value	Fuel Thickness CM Observed Avg = 258 Calculated Value	Fuel Thickness CM Observed High = 360 Calculated Value
Pd = 0.867 cm			
Farr	69.3	100.0	140.6
AF	70.8	102.4	143.2
Concave	53.6	77.2	107.8
Pd = 9.35 cm			
Farr	13.6	45.2	86.0
AF	13.5	45.2	85.9
Well W-01	Observed low = 294	Observed Avg = 342	Observed High = 448
Pd = 0.867 cm			
Farr	114.0	133.5	175.0
AF	116.8	136.0	178.0
Concave	88.0	102.4	134.1
Pd = 9.35 cm			
Farr	64.2	76.8	105.3
AF	59.6	78.7	121.0
Well W-05	Observed low = 30	Observed Avg = 314	Observed High = 426
Pd = 0.867 cm			
Farr	10.6	122.0	166.0
AF	1.2	124.8	169.6
Concave	8.9	94.0	127.5
Pd = 9.35 cm			
Farr	1.9	69.5	99.2
AF	-46.0	67.5	112.3

TABLE 19. OBSERVED VS CALCULATED THICKNESS, WILLIAMS WELLS W-09 & W-13 AT AIR-H_2O CAPILLARY HEADS OF 0.867 & 9.35 CM.

WILLIAMS AFB AZ Well W-09	Fuel Thickness CM Observed Low = 32 Calculated Value	Fuel Thickness CM Observed Avg = 224 Calculated Value	Fuel Thickness CM Observed High = 338 Calculated Value
Pd = 0.867 cm			
Farr	11.9	87.2	132.0
AF	12.0	88.8	134.4
Concave	9.6	67.1	102.0
Pd = 9.35 cm			
Farr	2.2	46.2	75.8
AF	-45.2	31.5	77.2
Well W-13	Observed Low = 34	Observed Avg = 156	Observed High = 259
Pd = 0.867 cm			
Farr	12.7	60.5	100.9
AF	12.8	61.6	102.8
Concave	10.2	46.7	77.6
Pd = 9.35 cm			
Farr	2.5	29.1	55.1
AF	-44.4	4.3	45.2

Figure 60. Williams AFB AZ Well LI-06
Observed vs Calculated Thickness



Oil-water surface tension = 15 dynes/cm

Figure 61. Williams AFB AZ Well LI-06 Observed vs Calculated Thickness

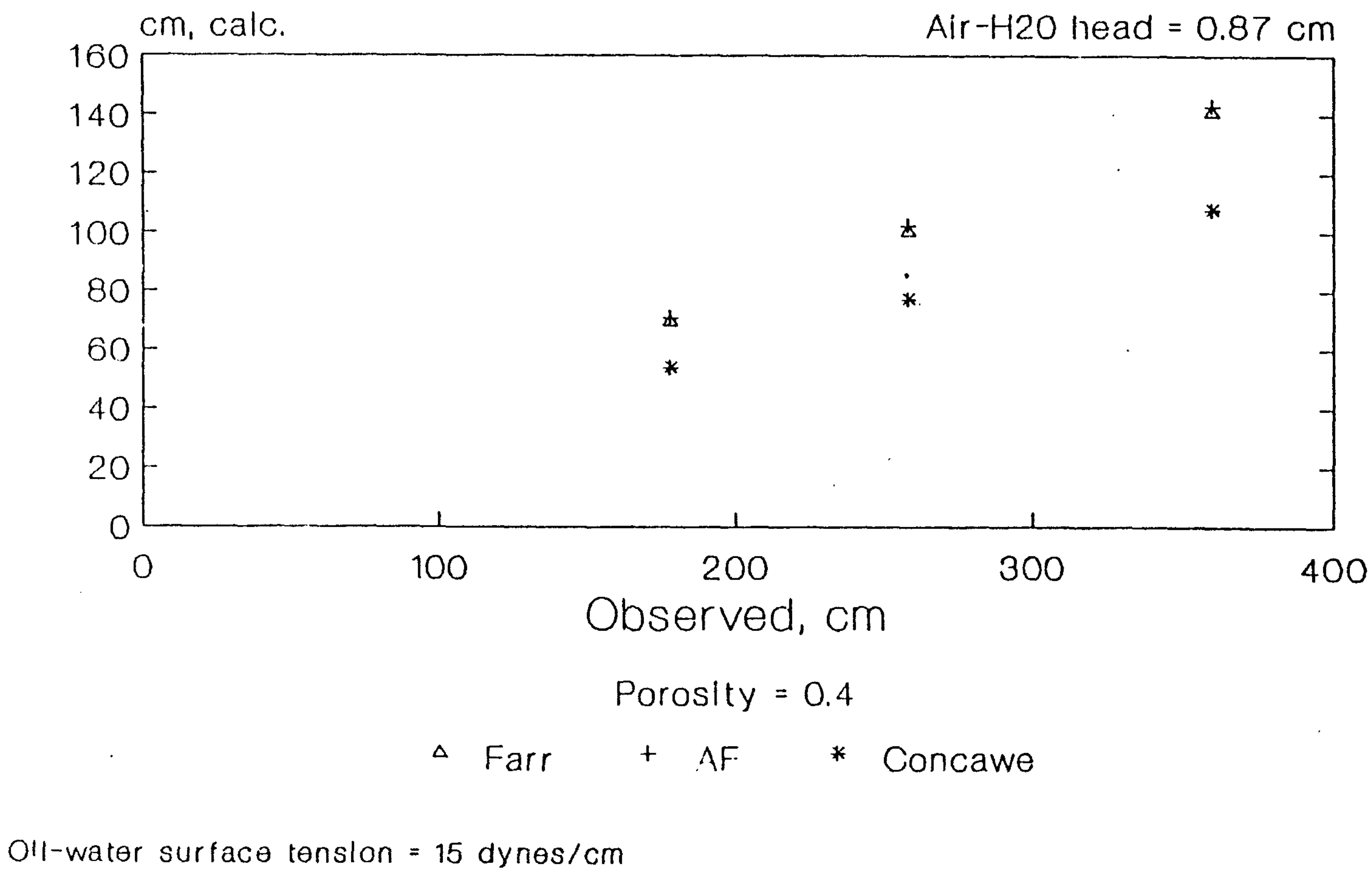


Figure 62. Williams AFB AZ Well W-01 Observed vs Calculated Thickness

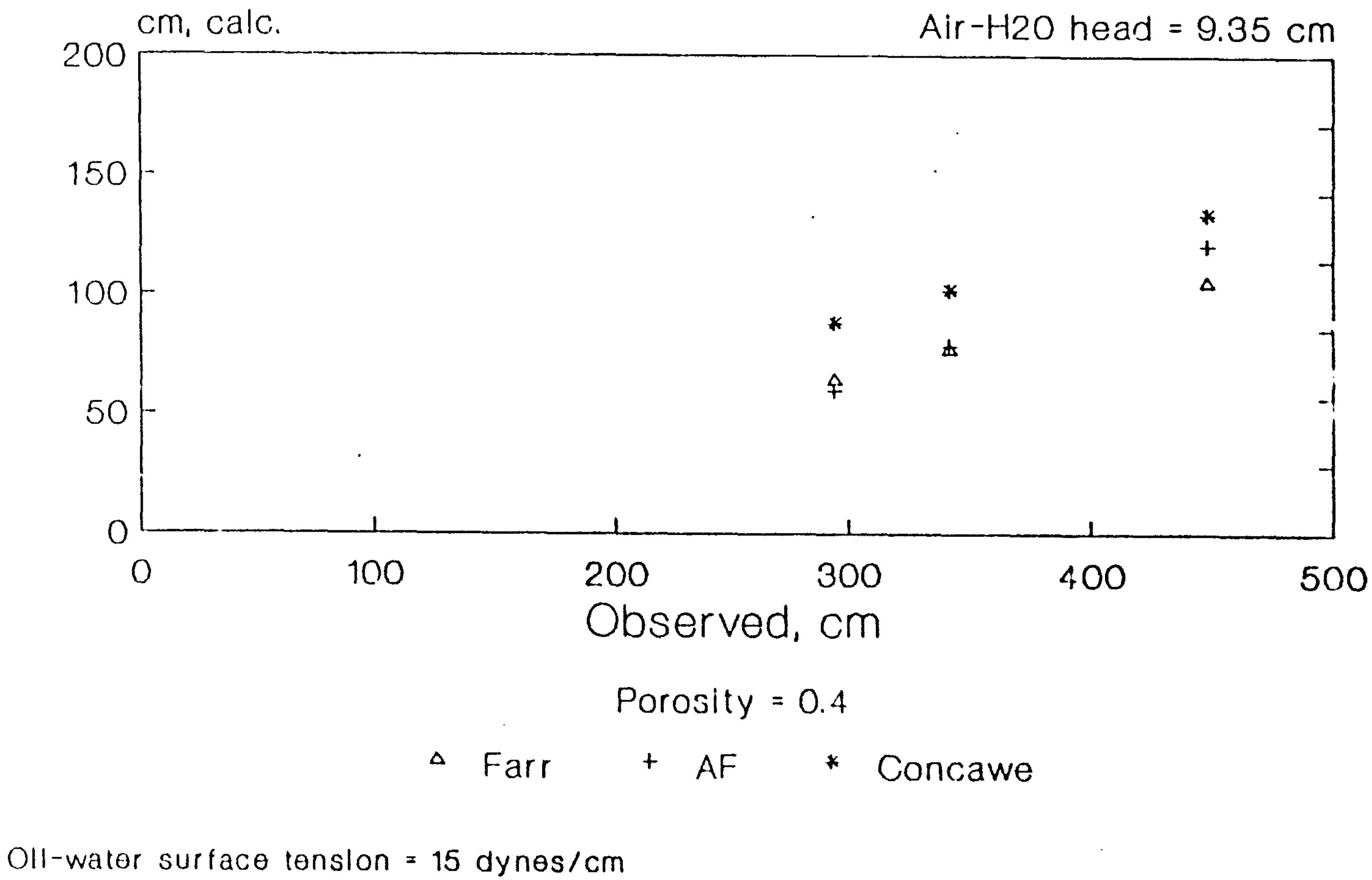
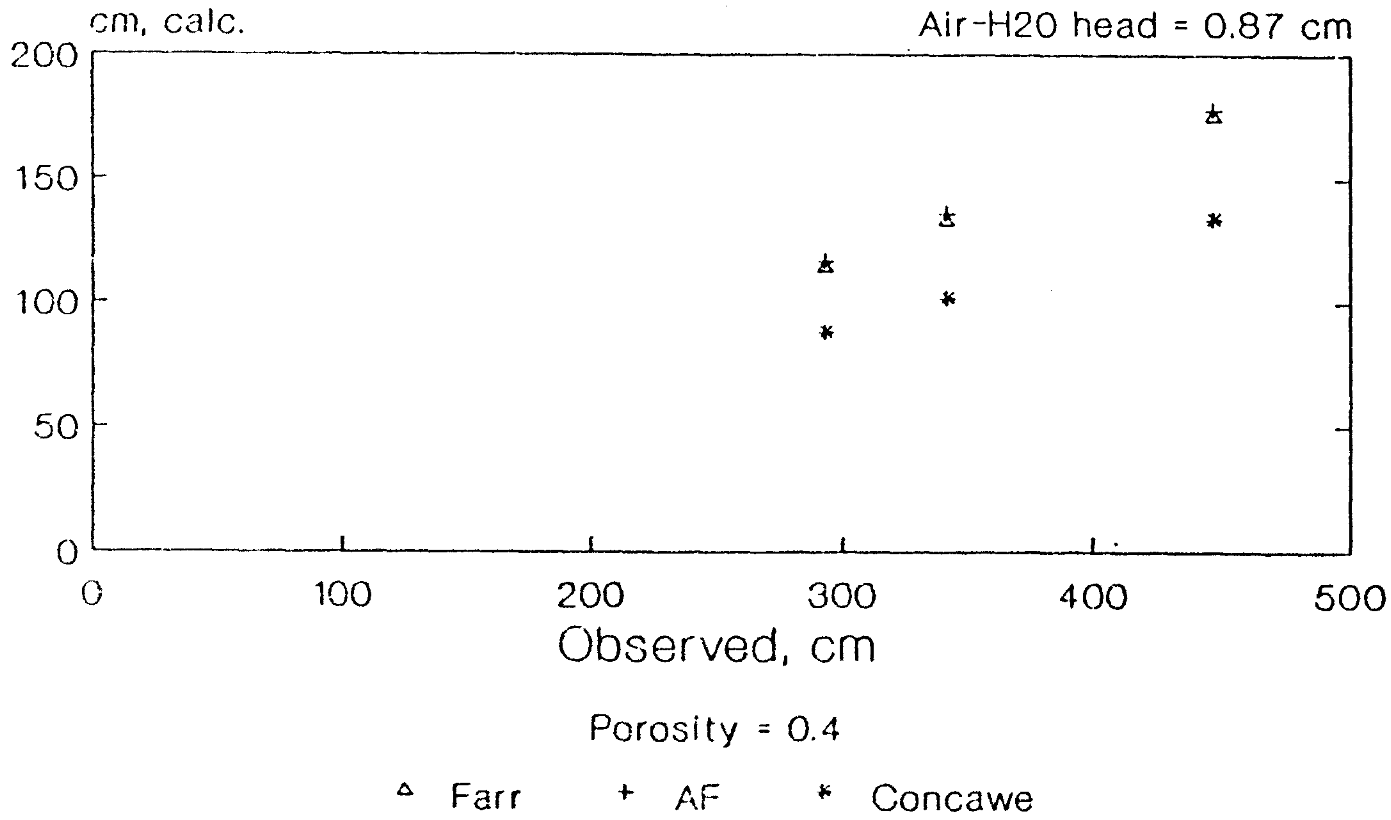


Figure 63. Williams AFB AZ Well W-01 Observed vs Calculated Thickness



Oil-water surface tension = 15 dynes/cm

Figure 64. Williams AFB AZ Well W-05 Observed vs Calculated Thickness

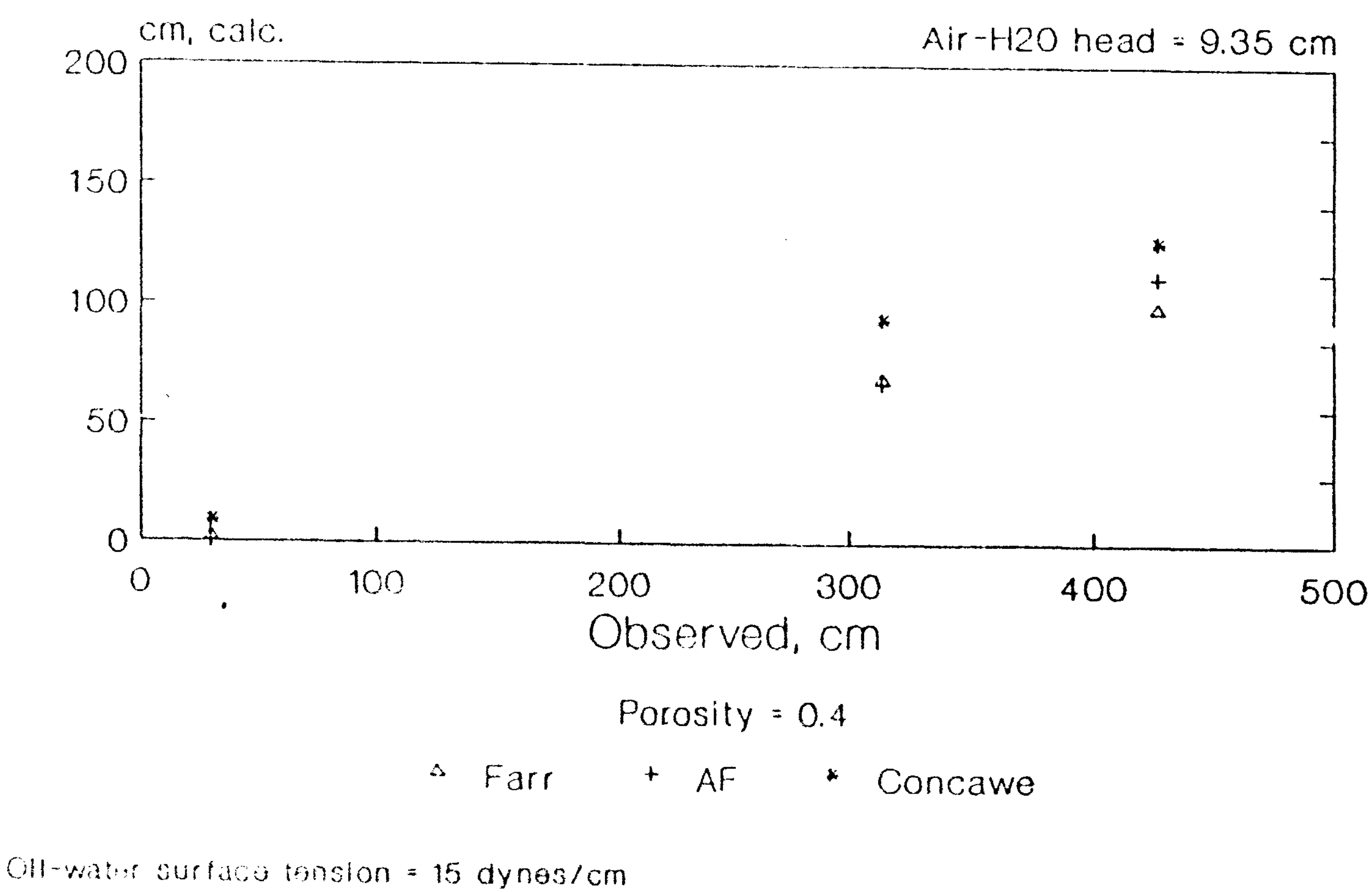


Figure 65. Williams AFB AZ Well W-05
Observed vs Calculated Thickness

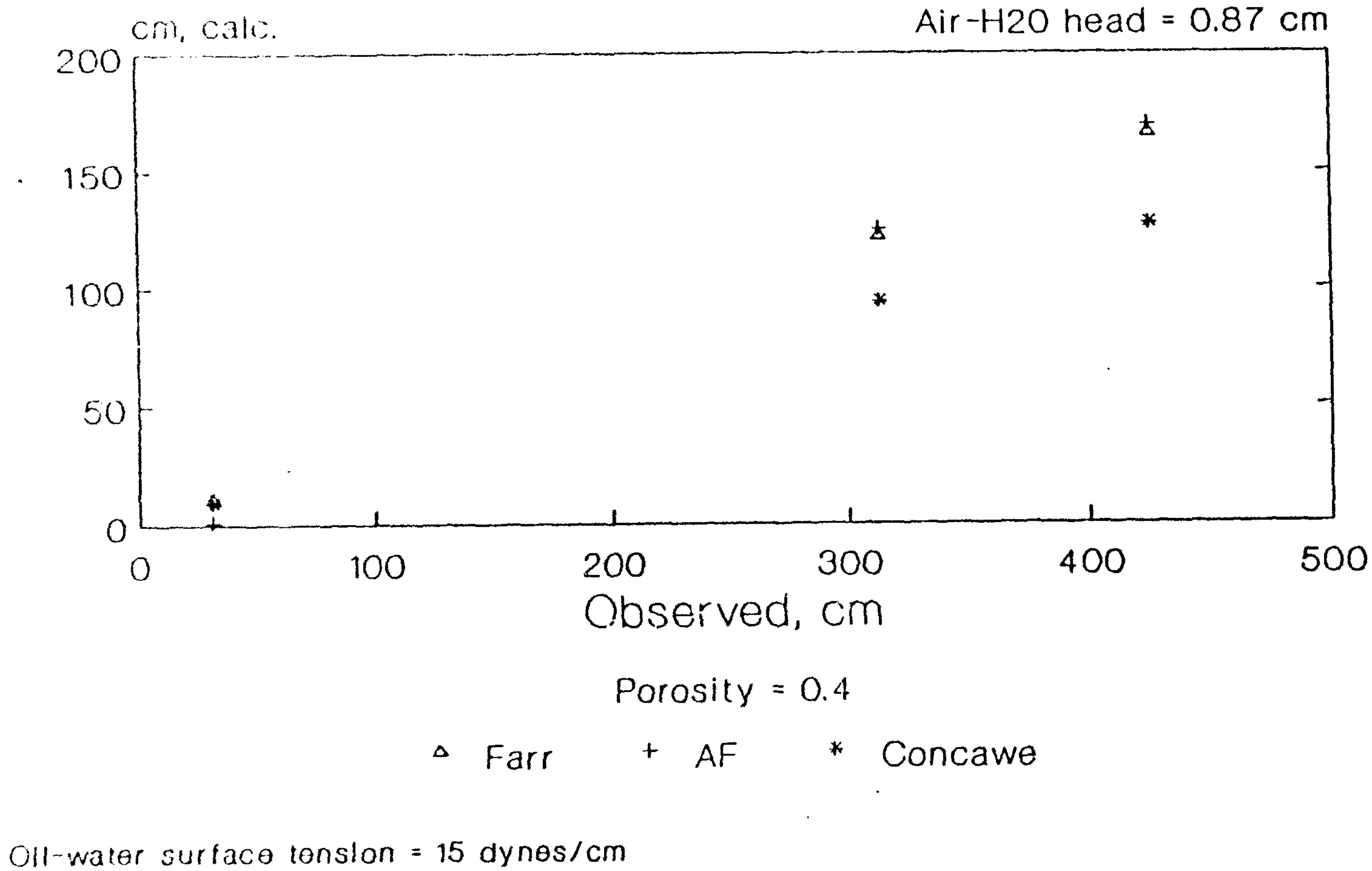


Figure 66. Williams AFB AZ Well W-09 Observed vs Calculated Thickness

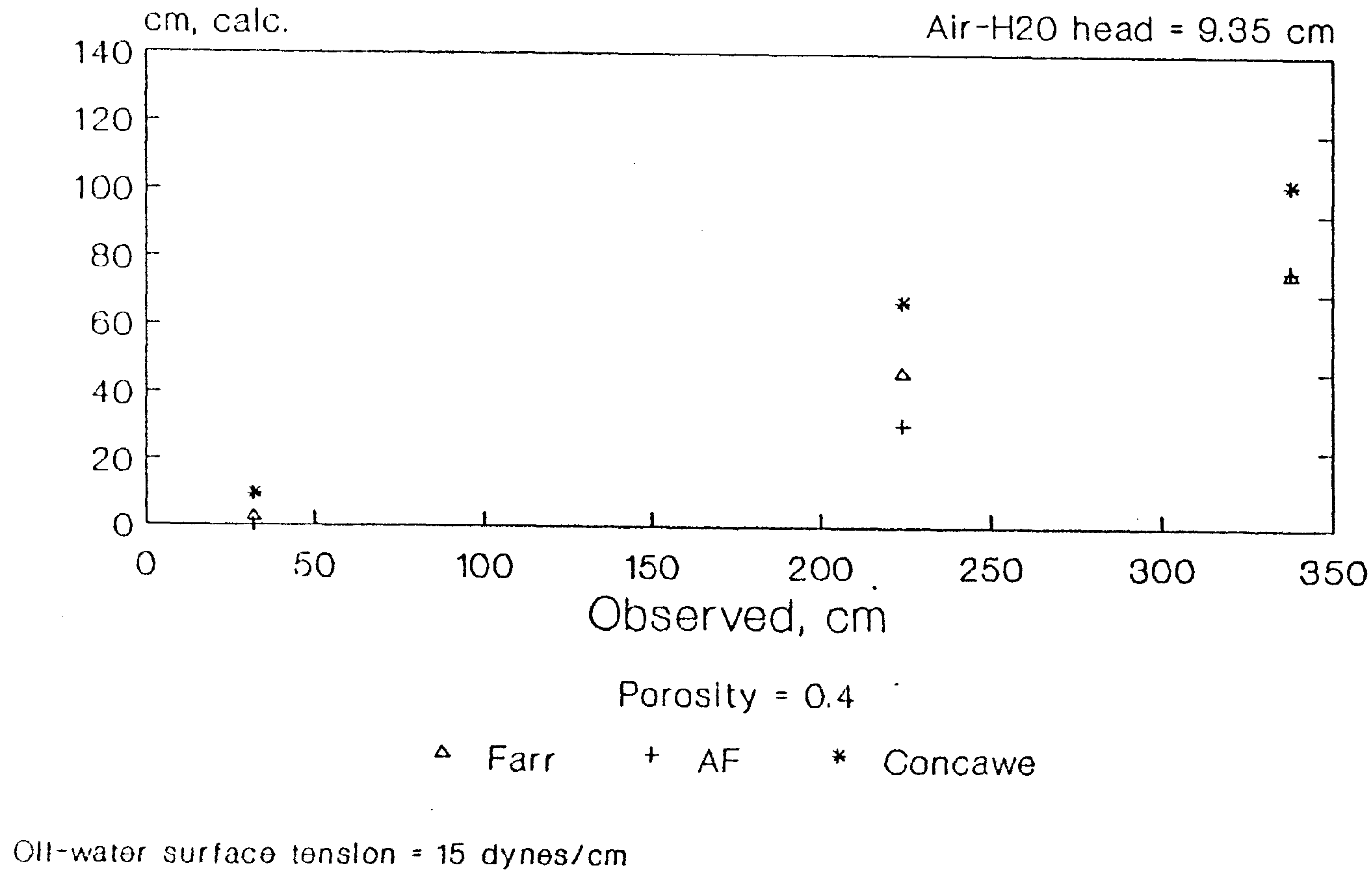
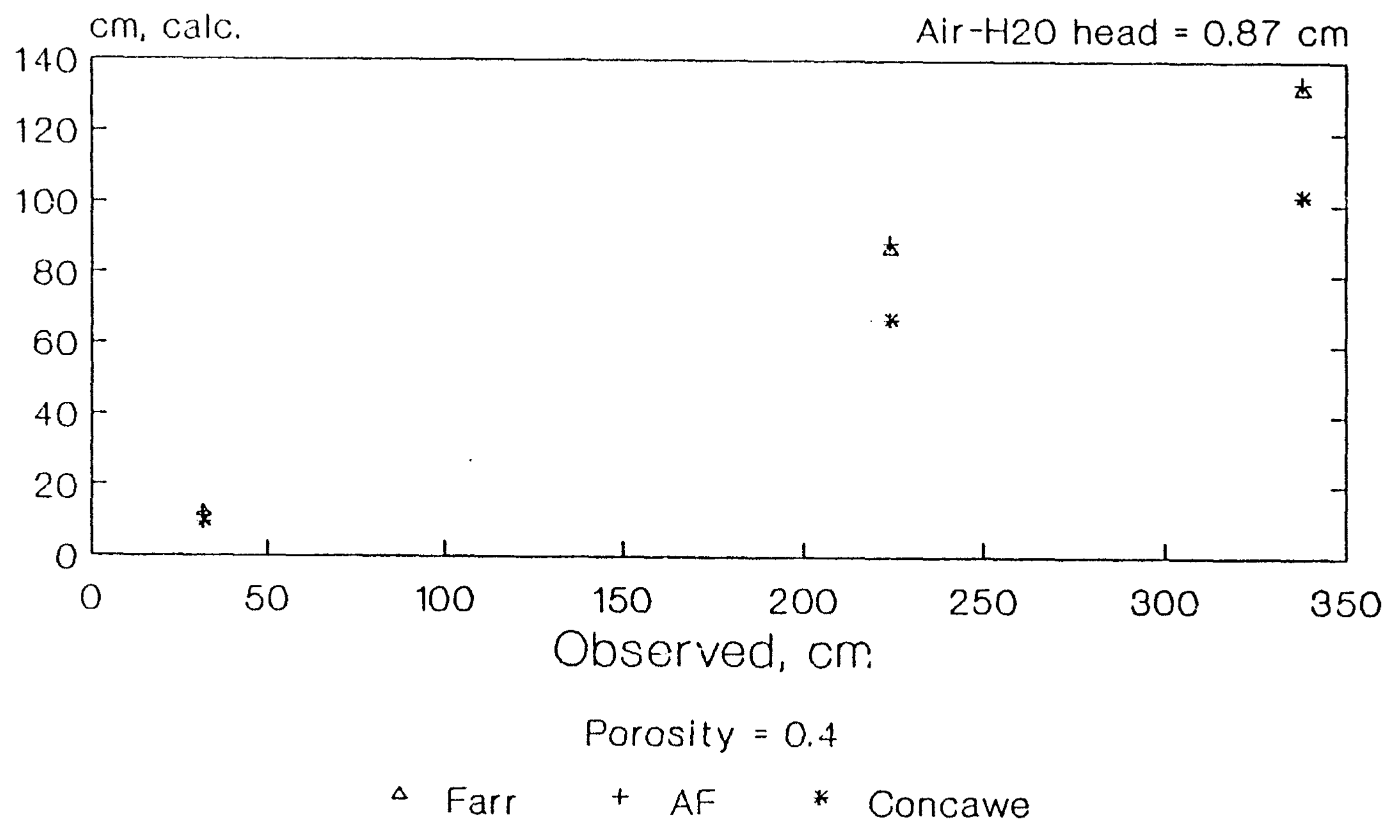


Figure 67. Williams AFB AZ Well W-09
Observed vs Calculated Thickness



Oil-water surface tension = 15 dynes/cm

Figure 68. Williams AFB AZ Well W-13 Observed vs Calculated Thickness

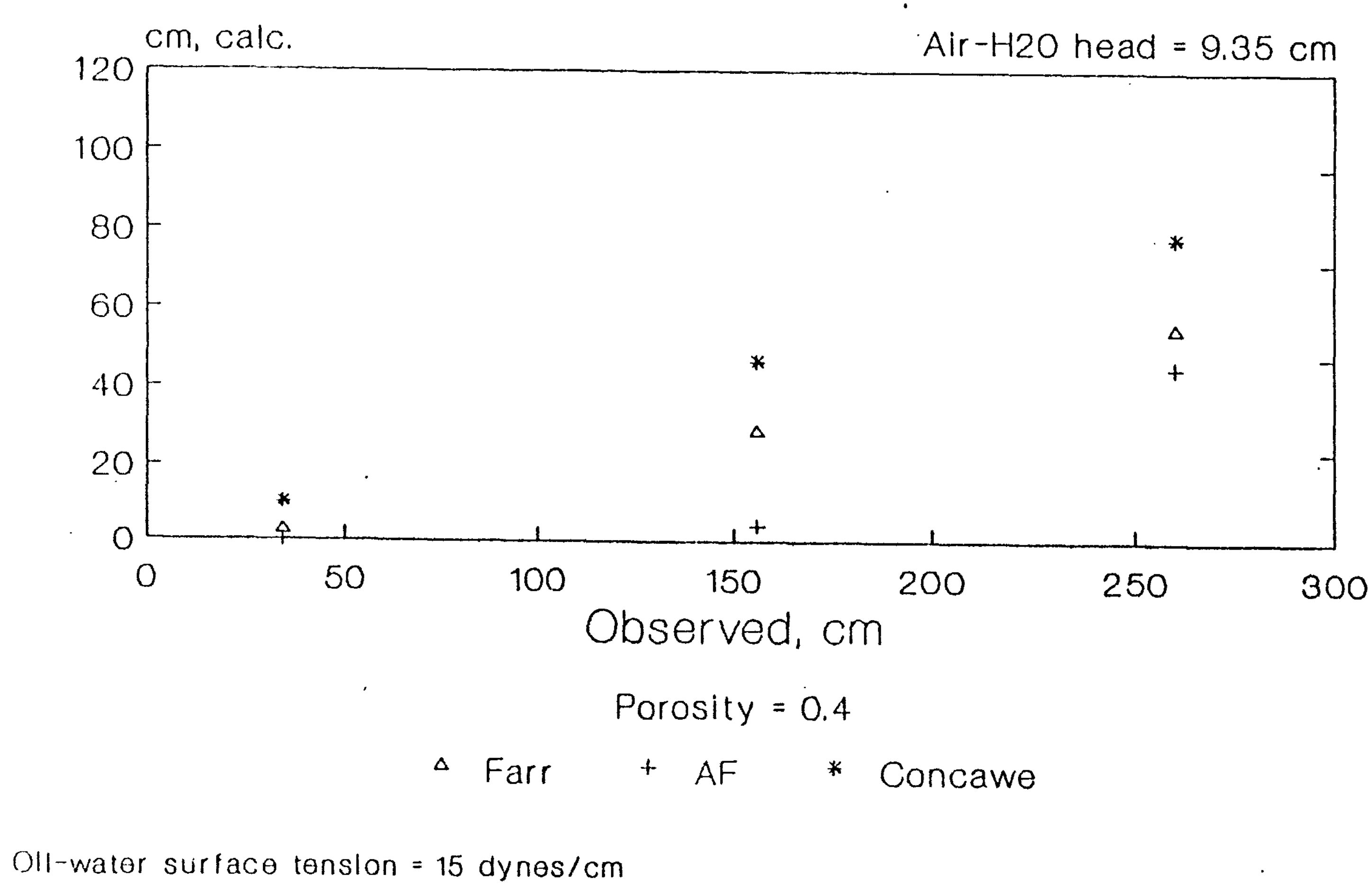
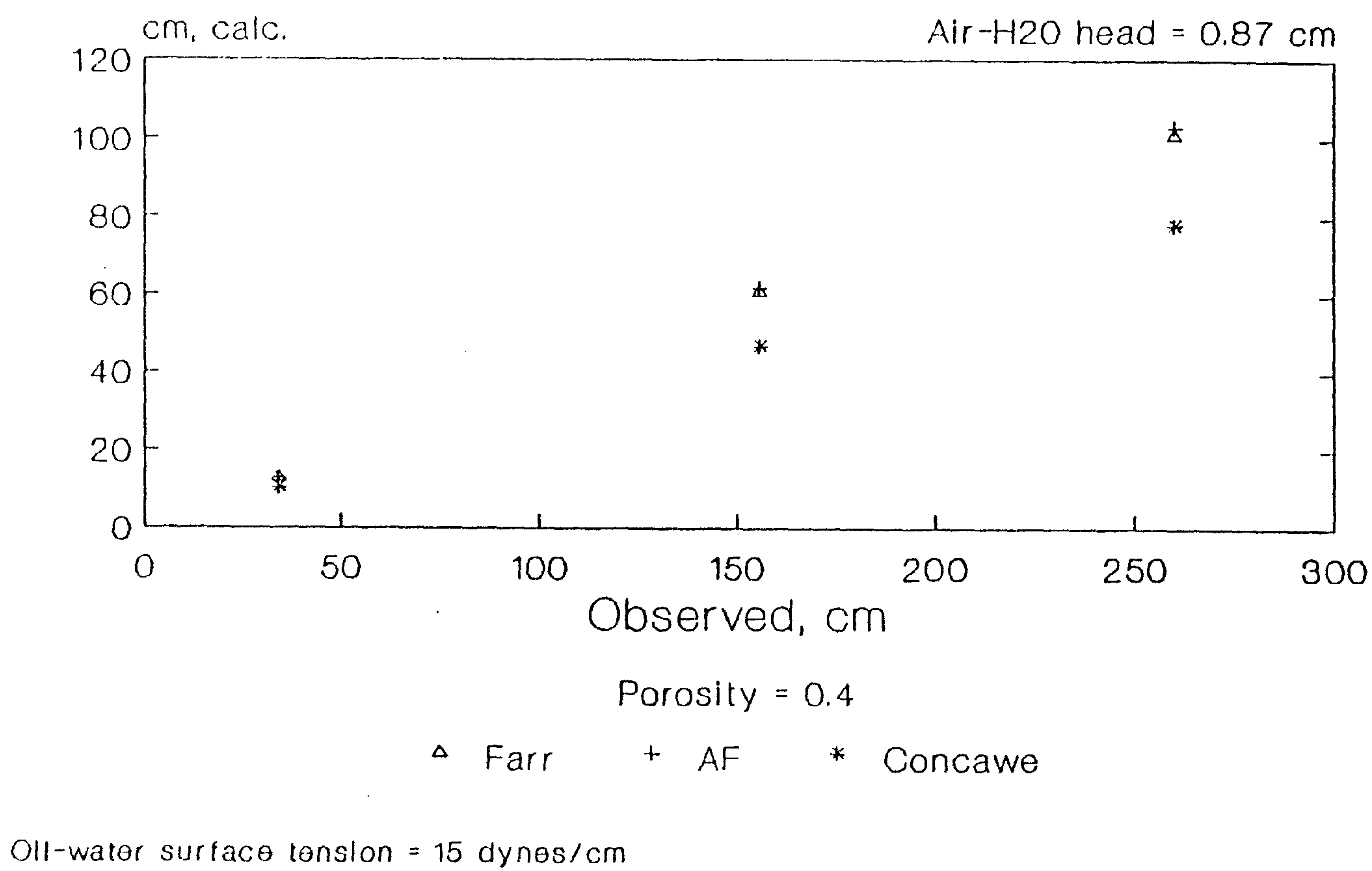


Figure 69. Williams AFB AZ Well W-13
Observed vs Calculated Thickness



EDWARDS AFB CA

SITE HISTORY

Base personnel discovered the presence of a floating layer of JP-4 fuel in October 1985 during an underground storage tank replacement project at a flightline service station. The site was further investigated during a subsequent Installation Restoration Program (IRP) Phase II investigation; thereafter the site was known as IRP site 17. Seventeen wells were developed at site 17 to ascertain the extent of the JP-4 plume, however free product has only appeared in the following three wells: well 1, 3, and 7. The extent of the JP-4 plume is thought to be less than 1.5 acres in area, at an average depth of 36 feet. A remedial action plan for site restoration has been submitted to the State of California as the JP-4 contamination affects the regional Antelope Hydrologic Unit. No free product has been recovered at this site as of September 1990. The IRP contractor has not established a volume estimate of the amount of JP-4 at this location (Edwards AFB 1986 IRP report).

GEOLOGY

The vadose zone at si+: 17 is characterized as fine to coarse sand (some cobbles and gravel present) with some clay grading to very coarse sand and gravel. The saturated zone is described as fine to very fine sand and clayey sand grading to clay and sandy clay. See Appendix 5, EDWARDS for the three well logs used for SOILPROP input as no particle size distributions (PSDs) were available for this location. After interpreting the well logs, the following inputs were made into SOILPROP: Wells 1 and 3, 10% fines, 20% fine sand, 50% medium sand, 10% coarse sand, and 10% fine gravel. Well 7: 25% fines, 25% fine sand, 35% medium sand, and 15% coarse sand.

OBSERVED JP-4 LEVELS

Civil Engineering personnel conducted sporadic measurements of the JP-4 layer from September 1989 to September 1990. See the EDWARDS Appendix for the table of the observed values. In general, the observed thickness of JP-4 has steadily increased over the period of monitoring. The depth to water table in all wells has generally increased over the period of monitoring by an average of 40 cm. The average observed thickness of the JP-4 at site 17 was 16.5 cm over the one year

period of monitoring. The average value of JP-4 observed in each well follows: Well 1; 13.5 cm, well 3; 5.8 cm, well 7; 30.3 cm. Well 7 shows considerably more JP-4 present than wells 1 and 3. The variation in observed thickness of JP-4 levels is shown in the table below:

TABLE 20. DIFFERENCES IN OBSERVED FUEL THICKNESSES - EDWARDS

Well	low (cm)	high (cm)	Difference (cm)
1	5.8	24	18.2
3	1.5	16	14.5
7	12.2	61	48.8

CALCULATED JP-4 LEVELS

Using the well logs as a source of particle size distribution (PSD) data, SOILPROP produced an air-water capillary fringe head (Pd^{aw}) of 1.8 cm for wells 1 and 3, and 1.95 cm for well seven. The difference in the values is due primarily to the differences in fines input, 10% for wells 1 and 3, 25% for well 7. The calculated values of JP-4 thickness in each well appears below using the condition of porosity set equal to 0.4 and oil-water surface tension (σ_{ow}) set equal to 15 dynes/cm.

TABLE 21. OBSERVED VS CALCULATED THICKNESS, ALL WELLS, EDWARDS

Method/Well	Thickness		
Well 1	low (cm)	average (cm)	high (cm)
Observed	5.8	13.5	24.0
Farr	0.88	3.0	6.2
AF	-4.0	-1.0	2.4
Concawe	1.7	4.0	7.2
Well 3			
Observed	1.5	5.8	16.0
Farr	-0.5	0.88	3.7
AF	-6.0	-4.0	0.0
Concawe	0.4	1.7	4.8
Well 7			
Observed	12.2	30.3	61.0
Farr	2.2	7.5	16.8
AF	-2.4	4.7	16.8
Concawe	3.6	9.1	18.3

As shown, the calculated values using the Concawe equation are linear using the Concawe 3.34 factor. The AF equation produces calculated thickness values that are negative, which is theoretically impossible. The negative fuel thickness values are not shown in Figures 70-72, however the values appear in Table 21 above. In this soil type it appears the

lower limit of observed thickness is around 16 cm before the calculated thickness is positive in value. This is a factor of the AF equation using the Brooks-Corey parameters of   and Sr. From observations by Farr et. al. (1990), the minimum thicknesses in soil from 10 to 98 cm of fuel were calculated before product appeared in wells. From observations in this study, the referenced numbers appear to be unreasonably large due to the fact observed thicknesses of 0.5 cm JP-4 appeared in wells. It was also noted by Farr that it is reasonable to assume significant quantities of fuel may exist in the vadose zone and are not manifest by the presence of fuel in monitoring wells due to soils exhibiting a finite entry pressure.

At the higher observed JP-4 levels at this site, there is good agreement between all three equations. As stated in earlier sections, correcting for specific retention using the AF and Farr equations may equate the calculated answers better to Concawe at lower observed thickness levels.

SITE CONCLUSIONS

GEOLOGY

Due to no exact particle size distributions being available for SOILPROP input, the generated Pd^{aw} result values could be quite variable. However there is good agreement between the two Pd^{aw} values generated due to the consistency in the well log information. Due to the porosity value of the saturated zone at this location being unknown, the calculated fuel thickness as presented in this section could be different by three to seven cm based on similar soil conditions (25% fines) as found at Langley AFB VA.

MEASUREMENTS OVER TIME

This site is a prime candidate for continuous monitoring due to the general increase of observed thickness of JP-4 in the monitoring wells. This fact is apparent when looking at the calculated average JP-4 thickness of one cm in well 1 using September 1989 data, compared to six cm using September 1990 data.

CALCULATED JP-4 THICKNESS AND σ_{ow} FACTORS

All of the calculations at this location were conducted at the σ_{ow} level of 15 dynes/cm. From results obtained at other sites in this study, we know the calculated fuel thickness increases dramatically with lower oil-water surface tension values. This would be expected at this location also. The calculated fuel thicknesses at this site should be considered being moderately to low in reliability. This is due mainly to the fact of having no PSD data from this site for SOILPROP input.

At this site, the Concawe equation consistently produced answers above the Farr and AF equations. Part of the range in answers may be explained by the fact that the Concawe equation gives an answer not taking into account the geologic formation, whereas the AF and Farr equations have corrections for porosity, and importantly, residual saturation (Sr) which SOILPROP assigned a value of 16% at this site. The Sr factor alone accounts for most of the spread in the answers of the three equations.

At this location, the Concawe equation may be the best estimator of the actual fuel thickness on the aquifer, due to the uncertainty attached to the AF and Farr equation parameters of porosity, oil-water surface tension, and PSD data.

Figure 70. Edwards AFB Site 17, Well 1
Observed vs Calculated Fuel Thickness

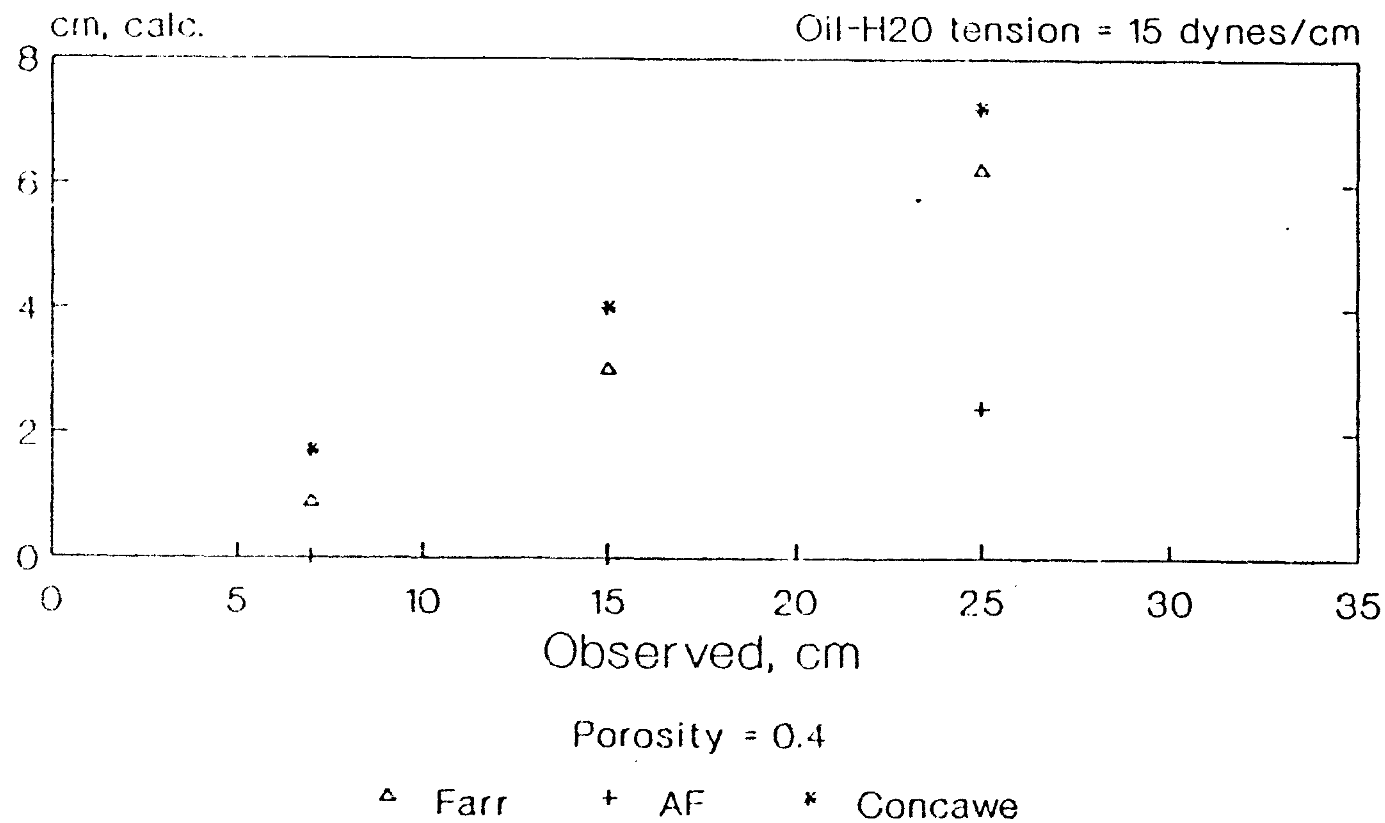


Figure 71. Edwards AFB Site 17, Well 3
Observed vs Calculated Fuel Thickness

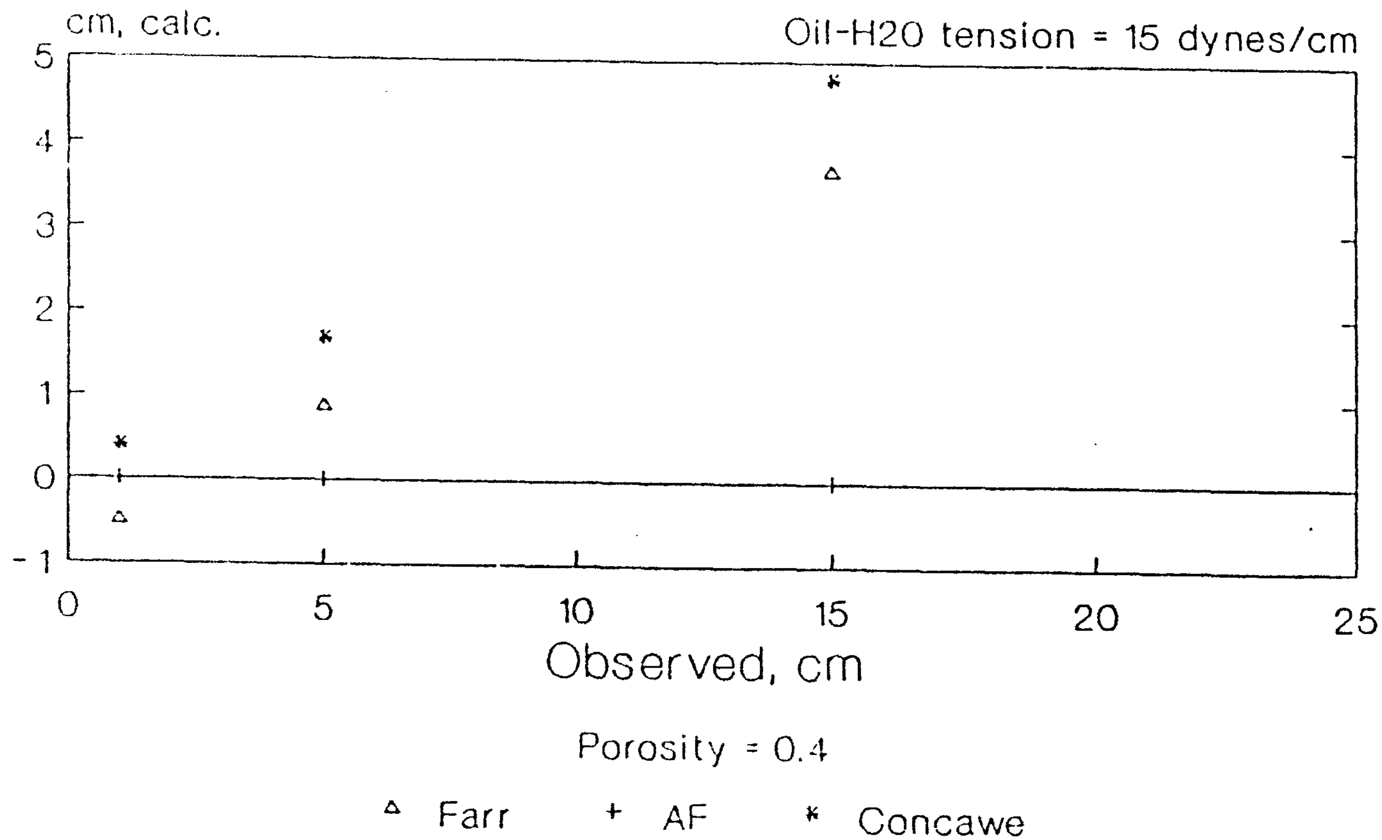
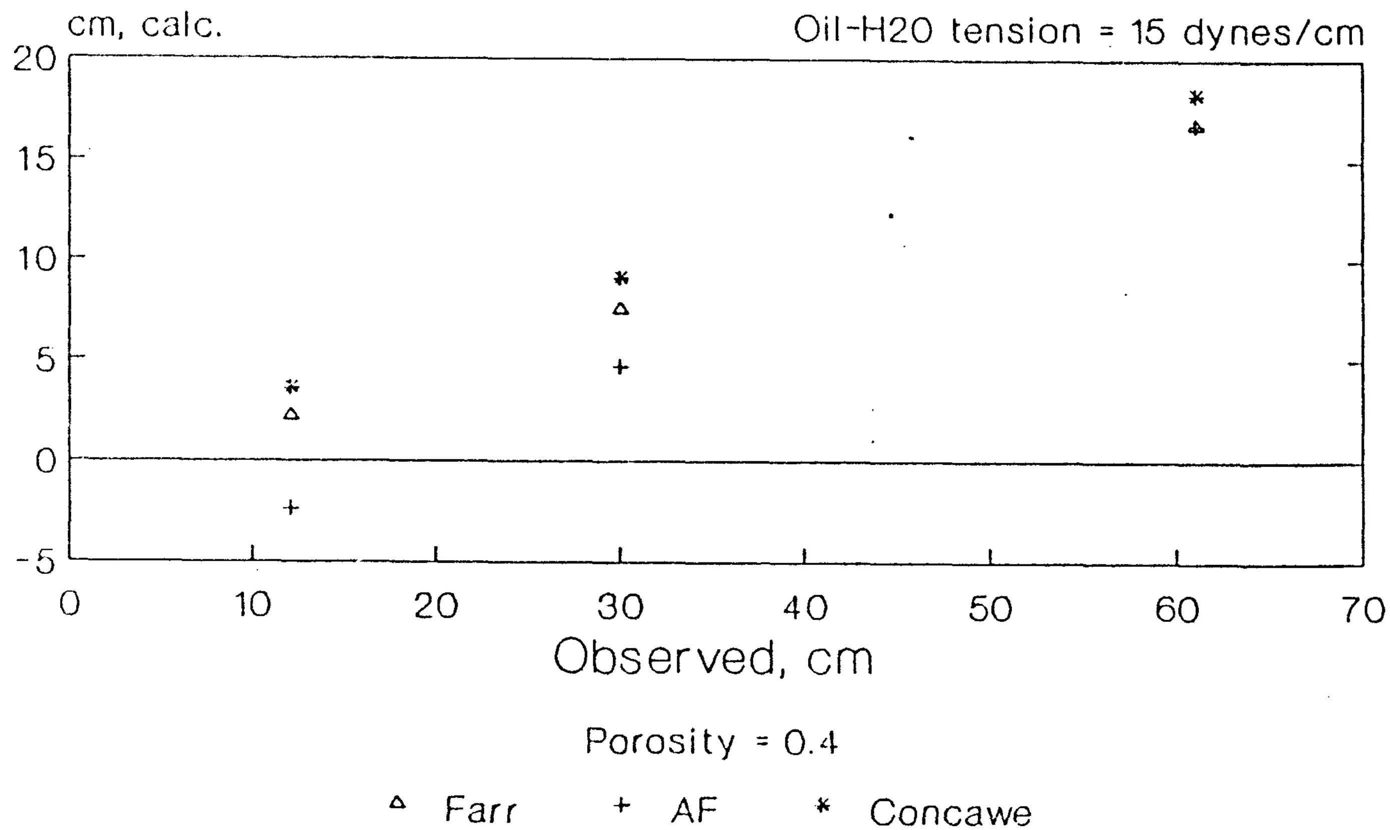


Figure 72. Edwards AFB Site 17, Well 7 Observed vs Calculated Fuel Thickness



COLUMBUS AFB MS

SITE HISTORY

In the Spring of 1985, base personnel discovered a floating layer of JP-4 near the Petroleum, Oil, and Lubricant (POL) storage area. Subsequently, the site became known to Installation Restoration Program (IRP) contractors as area 3, spill site (SS) 5. The source of the JP-4 was determined to be from leaking underground fuel distribution lines. Fifteen shallow monitoring wells were developed as SS 5 to determine the extent of the JP-4 plume. Free product has appeared only in the following three wells: wells 17, 41, and 42. See appendix 6, COLUMBUS for a map of the area and locations of the monitoring wells. The JP-4 plume has been estimated to cover 39,600 square feet of area at a depth ranging from 6.5 to 22 feet below grade. The IRP contractor has estimated the volume of JP-4 at this site to be approximately 21,000 gallons.

Remedial action of the site started in September 1990; as of 1 November 1990, 850 gallons of JP-4 has been recovered. Site restoration is expected to take at least two to three years (1989 Columbus AFB IRP report).

GEOLOGY

The vadose zone at SS-5 is described as clay, and silt mixed Unified Soil Classification (USC) of CL, grading to sand with gravel (SP) and silty sand (SM-CL). All three of the wells containing free product have their saturated zone described a bit differently. Well 17 is deeper than wells 41 and 42. Well 17 is screened from 13.5 to 28.5 feet below grade. The average depth to water in well 17 over the period of monitoring was 22,4 feet. The saturated zone of well 17 is described as sand and gravel with silt (GM), grading to sand (SP) and finally clay (CL). The average depth to water in well 41 was 8.6 feet; it is screened from 7 to 20 feet. The saturated zone of well 41 is characterized as gravel containing less than 5% silt (GW) grading to sand containing 5% gravel (SP), finally to clay (CL). Well 42 is screened from 3 to 18 feet below grade, the average depth to water in the well over the monitoring period was 6.8 feet. The saturated zone of well 42 is described as clay (CL) grading to fine and medium sand, (SP), terminating at clay (CL).

All three of the well logs were available for assessment, however no particle size distribution was available for the location at the depths of interest. The entire area of SS-5 is underlain by the Eutaw Clay Formation at an average depth of 32 feet below grade, (1989 Columbus AFB IRP report).

After assessment of the well logs, the following inputs were made into SOILPROP: Well 17; 10% fines, 25% fine sand, 25% medium sand, 30% coarse sand, and 10% gravel. Well 41; 3% fines, 17% medium sand, 20% coarse sand, and 60% gravel. Well 42; 60% fines, 20% fine sand, and 20% medium sand.

OBSERVED JP-4 LEVELS

Civil engineering personnel conducted sporadic monitoring of the floating layer of JP-4 from May 1989 to May 1990. The differences in the average thickness of JP-4 observed in the three monitoring wells was great. The readings obtained from well 17 appear to be almost independent from the data from wells 41 and 42. The average thickness of JP-4 over the one year of monitoring was 108 cm in well 17, 34 cm in well 41 and 44 cm in well 42. The lowest level of JP-4 observed at SS-5 was 5 cm in well 41 (30 June 89). The highest level observed was 134 cm in well 17 on 2 March 1990. Due to the great difference in the average observed thickness levels between the three wells, it would not be appropriate to make an average thickness determination level for the entire site.

The differences of fuel levels observed in each well was large as indicated in the table below:

TABLE 22. DIFFERENCES IN OBSERVED FUEL THICKNESSES - COLUMBUS

Well	low (cm)	high (cm)	Difference (cm)
17	91.0	134.0	43.0
41	6.0	52.0	46.0
42	20.0	86.0	66.0

CALCULATED JP-4 THICKNESS LEVELS

Using the well log descriptions of the soil characteristics and interpreting the USC codes for particle sizes, SOILPROP produced the following air-water capillary heads (Pd^{aw}):

TABLE 23. Pd^{aw} and S_r VALUES AT VARYING POROSITIES - COLUMBUS

Well 17	Pd^{aw} (cm)	Sr
Porosity 0.4	0.89	0.105
Well 41		
Porosity 0.4	0.122	0.012
Well 42		
Porosity 0.25	5.59	0.182
Porosity 0.3	5.14	0.216
Porosity 0.35	4.58	0.25
Porosity 0.4	4.12	0.283
Porosity 0.45	3.72	0.315

S_r = residual saturation of water, used in the Farr equation.

Table 24 on the following two pages states the calculated JP-4 thickness levels using the different equations at the different porosities and oil-water surface tensions (well 42 only). Figures 73-83 illustrate the tabled values.

At this location the trend of greater calculated thickness of fuel with increasing porosity is apparent, as is the trend of increased calculated fuel thickness with lower surface tensions of the fuel-water interface. The results of the Concawe equation again indicates a linear relationship between observed and calculated fuel levels. Referring to the baseline data, well 17 shows the range of calculated values at the 108 cm level (average thickness) between all three equations to be nine cm, but at the 134 cm level, the spread decreases to 6.2 cm, with the Concawe value at the low end. The range of calculated answers at the average level for well 41 is even closer than the range found for well 17. In this geologic environment there is good agreement in calculated answers in the soil formations with fewer fines present. Again, the results of the Concawe equation are linear over all thicknesses; the answer may be interpreted as having all of the computed thickness available for recovery, whereas the AF and Farr equations in this soil type (at porosities above 0.3) reveal answers slightly above the Concawe answer. Correction factors may still be applied to the AF and Farr equation answers (15-30%) realizing that the entire computed volume may

TABLE 24. OBSERVED VS CALCULATED FUEL THICKNESS, COLUMBUS WELLS 42, 41 AND 17.

COLUMBUS AFB MS Well 42	Fuel Thickness CM Observed Low = 20.0 Calculated Value	Fuel Thickness CM Observed Avg = 44.0 Calculated Value	Fuel Thickness CM Observed High = 86.0 Calculated Value
Porosity = 0.25			
Farr at 20 dynes/cm	1.4	5.4	12.5
Farr at 15	2.0	6.2	14.0
Farr at 10	3.2	7.7	16.0
AF at 20	-.9	4.0	15.7
AF at 15	1.2	7.2	17.7
AF at 10	3.5	9.5	20.0
AF at 5	6.2	12.2	22.7
CONCAWE	6.0	13.2	25.7
Porosity = 0.3			
Farr at 20	1.7	6.1	14.6
Farr at 15	2.5	7.3	16.2
Farr at 10	3.7	9.0	18.6
AF at 20	-1.2	5.9	18.5
AF at 15	1.7	9.0	21.6
AF at 10	3.7	10.8	23.5
AF at 5	6.9	14.1	26.7
Porosity = 0.35			
Farr at 20	2.1	6.9	16.5
Farr at 15	2.8	8.2	17.9
Farr at 10	4.1	10.0	20.7
AF at 20	-.5	7.9	22.6
AF at 15	2.0	10.4	25.1
AF at 10	5.0	12.5	28.1
AF at 5	8.5	15.9	31.6

TABLE 24. OBSERVED VS CALCULATED FUEL THICKNESS, COLUMBUS WELLS 42, 41 AND 17 (CONTINUED).

COLUMBUS AFB MS Well 42	Fuel Thickness CM Observed Low = 20.0 Calculated Value	Fuel Thickness CM Observed Avg = 44.0 Calculated Value	Fuel Thickness CM Observed High = 86.0 Calculated Value
Porosity = 0.4			
Farr at 20 dynes/cm	2.3	7.7	18.1
Farr at 15	3.2	9.0	20.0
Farr at 10	4.5	11.0	22.6
AF at 20	-.4	9.2	26.0
AF at 15	2.4	12.0	28.8
AF at 10	5.7	15.0	31.8
AF at 5	9.6	19.2	36.0
Porosity = 0.45			
Farr at 20	2.7	8.4	19.5
Farr at 15	3.7	9.7	21.4
Farr at 10	4.9	11.8	24.2
AF at 20	-.3	10.5	29.4
AF at 15	2.8	13.6	32.5
AF at 10	6.4	17.2	36.1
AF at 5	10.7	21.5	40.4
Well 17	Observed low = 91	Observed Avg= 108	Observed High = 134
Porosity = 0.4			
Farr at 15 dynes/cm	29.3	35.1	44.0
AF at 15	29.3	36.1	46.3
Concawe	27.2	32.3	40.1
Well 41	Observed Low = 6.0	Observed Avg = 34.0	Observed High = 52.
Porosity = 0.4			
Farr at 15 dynes/cm	1.9	12.5	19.4
AF at 15	1.1	12.3	19.6
Concawe	1.8	10.1	15.6

not be recoverable as free product. The best fit of the calculated Concawe answer to the wide range of porosities and oil-water surface tension (σ_{ow}) for well 42 using the AF and Farr equations appears to be: Farr at porosity 0.4, σ_{ow} of 10 dynes/cm; AF, porosity 0.35, at σ_{ow} of 10 dynes/cm.

SITE CONCLUSIONS

GEOLOGY

The range of answers obtained using the three equations varies greatly and is dependent on accurate geologic information being available. The geology of site SS-5 at Columbus AFB MS changes quickly and is very complicated over short distances. The only certainty of this location is the existence of the Eutaw Clay Formation at a depth of 28-32 feet under the entire site. This fact may be important in the long term aspects of site restoration, however the layers of clay in the upper regions of the saturated zone make the fuel volume estimation problem very uncertain at this site. For this reason, and the fact no particle size distributions were available from the wells, made the SOILPROP inputs moderately uncertain. This fact is apparent in the percentage of fines at the oil-water interface level between the three wells ranged from 3-60%. More than any other factor, the percentage of fines influences the Pd^{aw} head generated by SOILPROP. One may assume taking a

mid range estimate for the percentage of fines at this site may be reasonable when applying the AF and Farr equations.

POROSITY

Having the correct porosity available for any location is of paramount importance. For example, the average thickness of JP-4 calculated for well 42 differs 3-9 cm from a porosity of 0.25 to 0.45. The degree of certainty associated with the AF and Farr equations could be strengthened simply knowing the true porosity (within 5%) of the oil-water interface zone.

OIL-WATER SURFACE TENSION

The variability of calculated thicknesses is shown in the parameter of oil-water surface tension (σ_{ow}). This is shown at all porosities to differ four to ten cm at the average fuel level. Again, the strength of the AF and Farr equations could be made greater by having the fuel in question analyzed for surface tension.

CALCULATED JP-4 THICKNESS

Due to the unknown inputs of porosity, particle size distributions and fuel age (relating to σ_{ow}), the calculated fuel thicknesses at this location vary widely. For example,

at the average observed thickness of 44 cm, well 42 reveals calculated thicknesses ranging from 5.1 cm (porosity = 0.25, σ_{ow} of 20 dynes/cm) to 21.5 cm (porosity = 0.45, σ_{ow} of 5.3 dynes/cm).

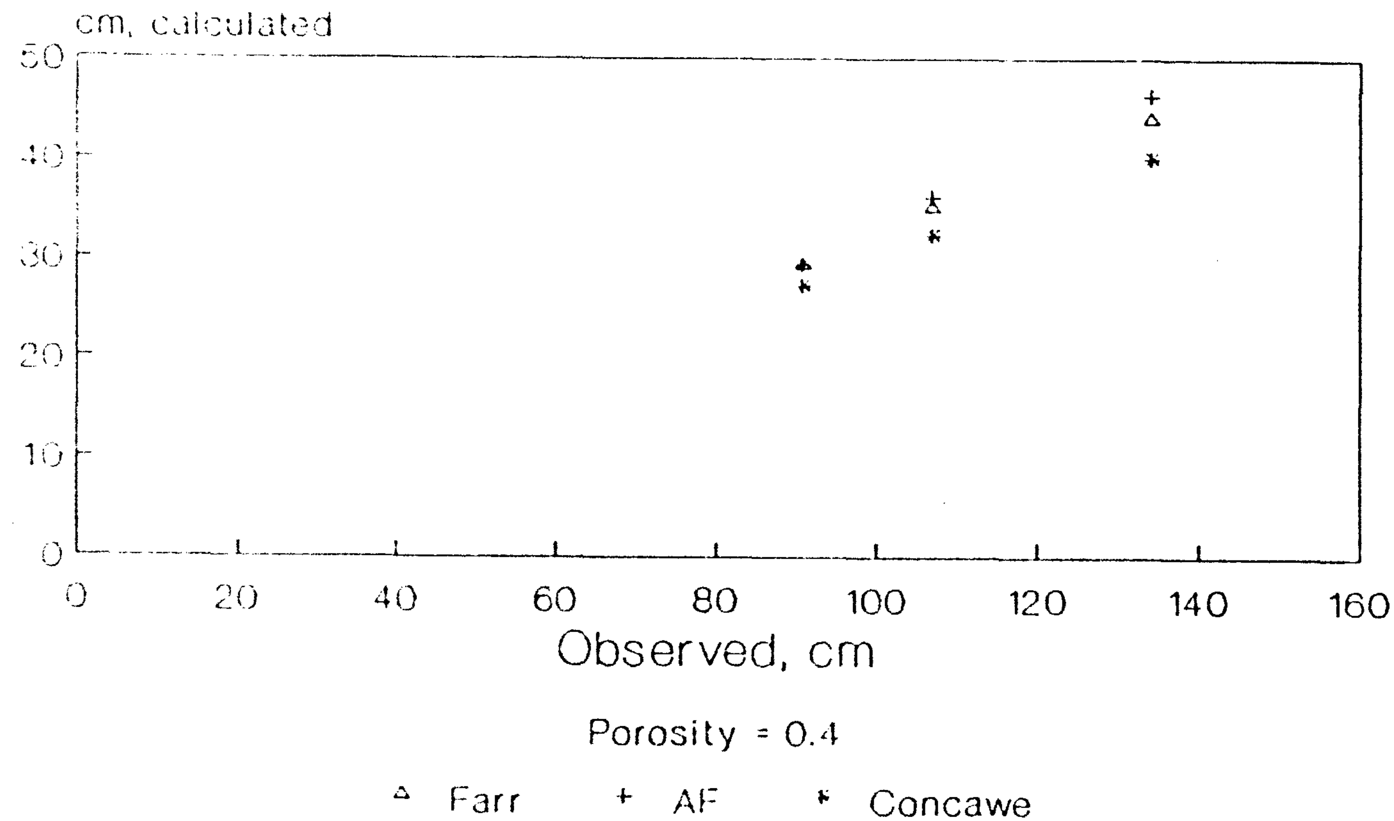
Using the IRP contractors estimate of 39,600 square feet (36,788,400 cm^2) area of the JP-4 plume, JP-4 estimations range from 187,620 liters (49,569 gallons) to 790,950 liters (208,970 gallons).

These answers are two to ten times the volumes the IRP contractor predicted for this site. No correction for residual saturation (Sr) are made for these answers, which may lower the computed answers 15-20%. The IRP contractor used an observed thickness of 11 cm, at a porosity of 0.20, and a Concawe factor of 4.0, which yields smaller computed answers, whereas the volumes estimated above are based on the average thickness over one year, 44 cm, at the conditions stated.

The point of the above statements is to reveal the fact of the wide ranging answers that result from computing JP-4 thickness in aquifer materials using the parameters of observed fuel thickness, σ_{ow}, porosity, and corrections for retention of the liquid in the soil formation.

At this location, the Concawe equation may be the most best estimator of the actual fuel thickness on the aquifer due to the unknown parameters of porosity, σ_{ow}, and particle size data. From information provided to this researcher, a more accurate determination cannot be made of the actual fuel thickness at this site.

Figure 73. Columbus AFB SS-5, Well 17
Observed vs Calculated Thickness



Oil-water surface tension = 15 dynes/cm

Figure 74. Columbus AFB SS-5, Well 41
Observed vs Calculated Thickness

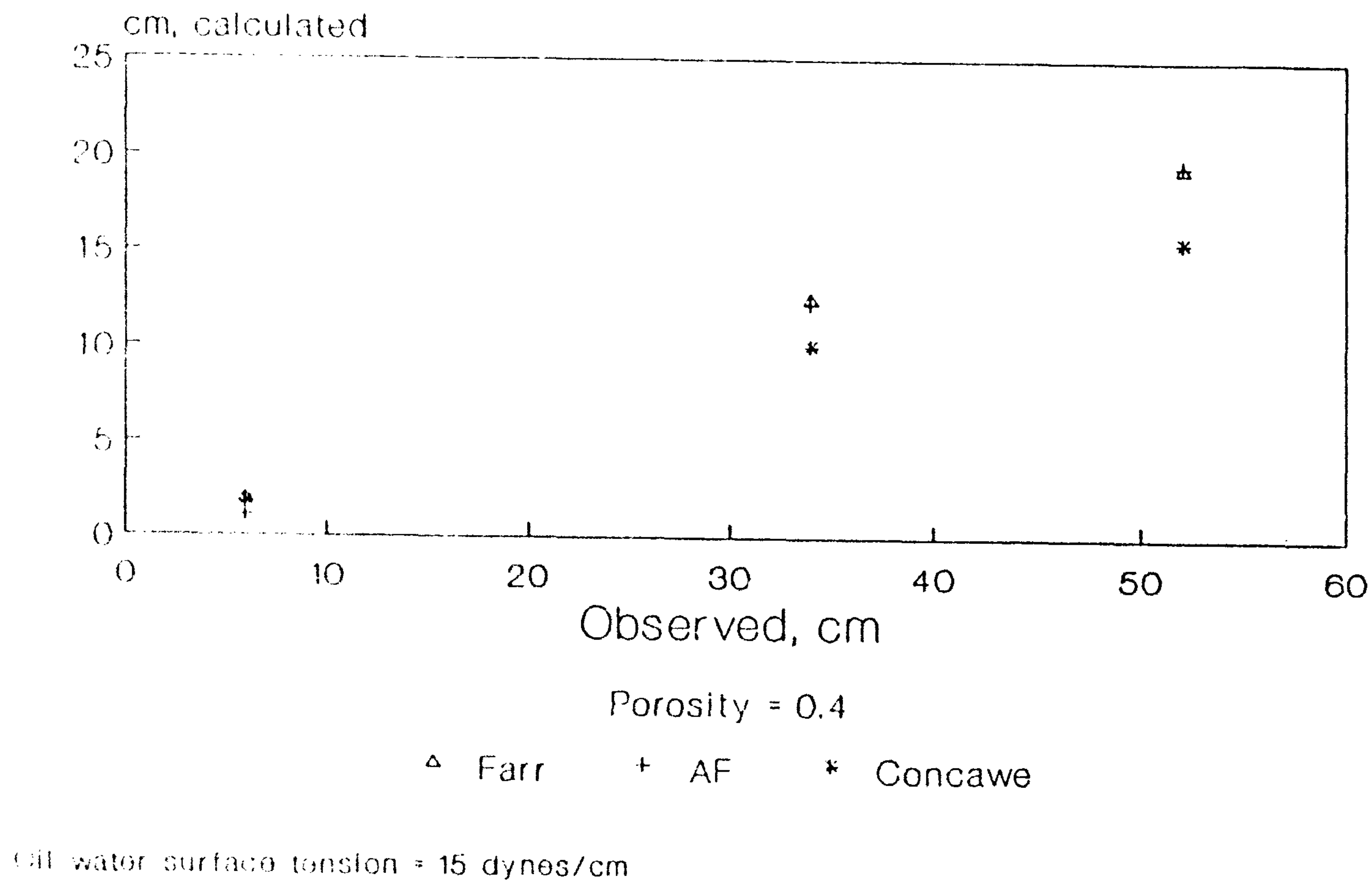


Figure 75. Columbus AFB SS-5, Well 42
Observed vs Calculated Thickness

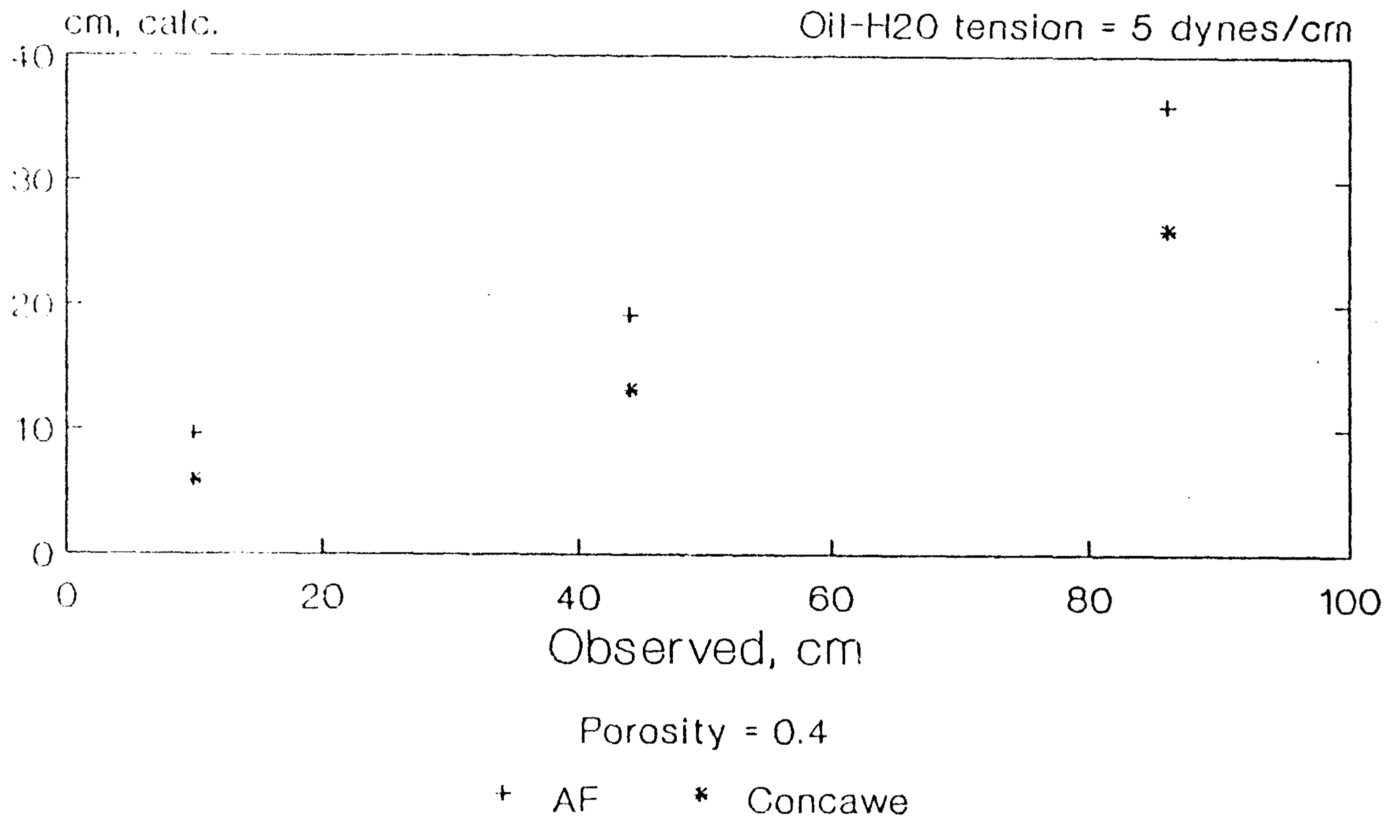


Figure 76. Columbus AFB SS-5, Well 42 Observed vs Calculated Thickness

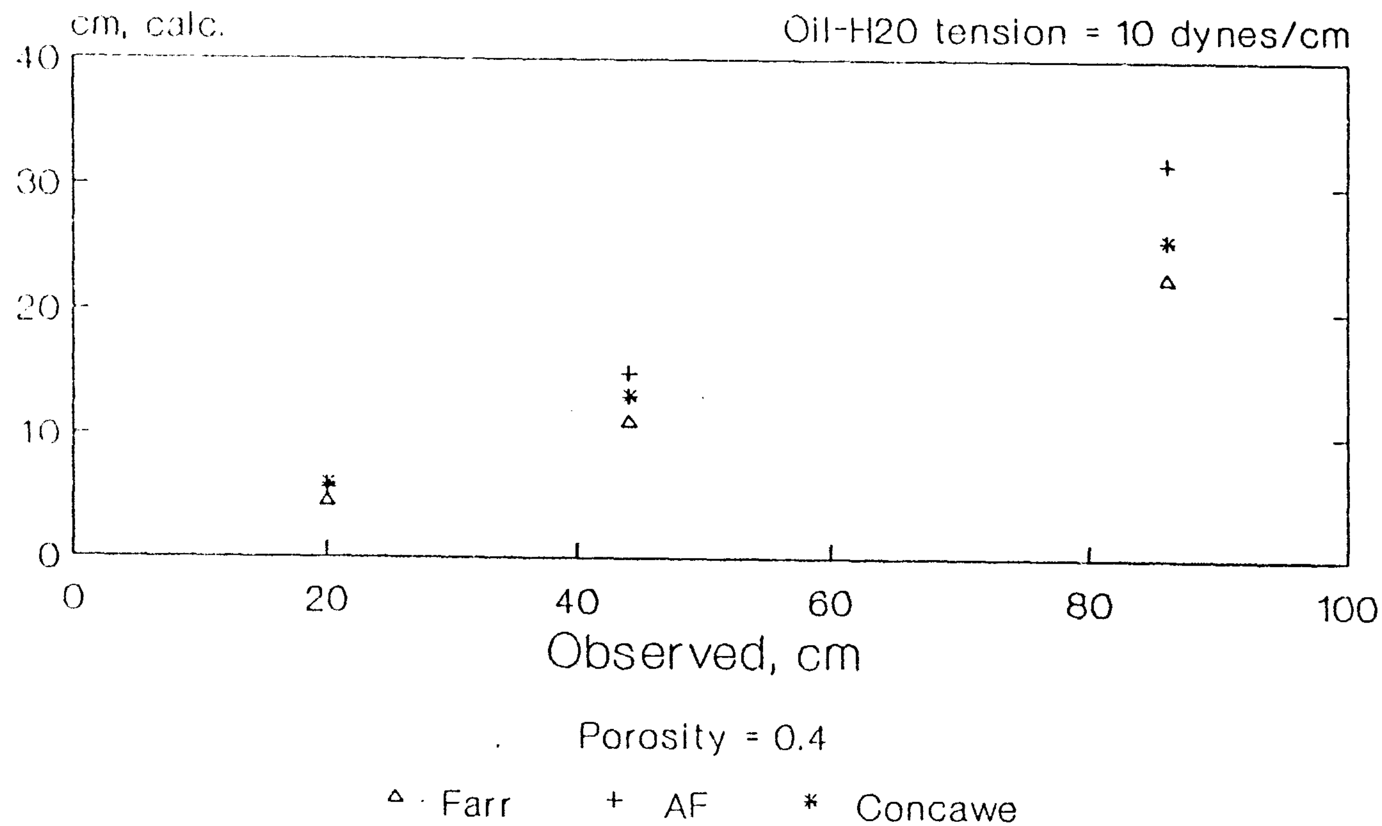


Figure 77. Columbus AFB SS-5, Well 42
Observed vs Calculated Thickness

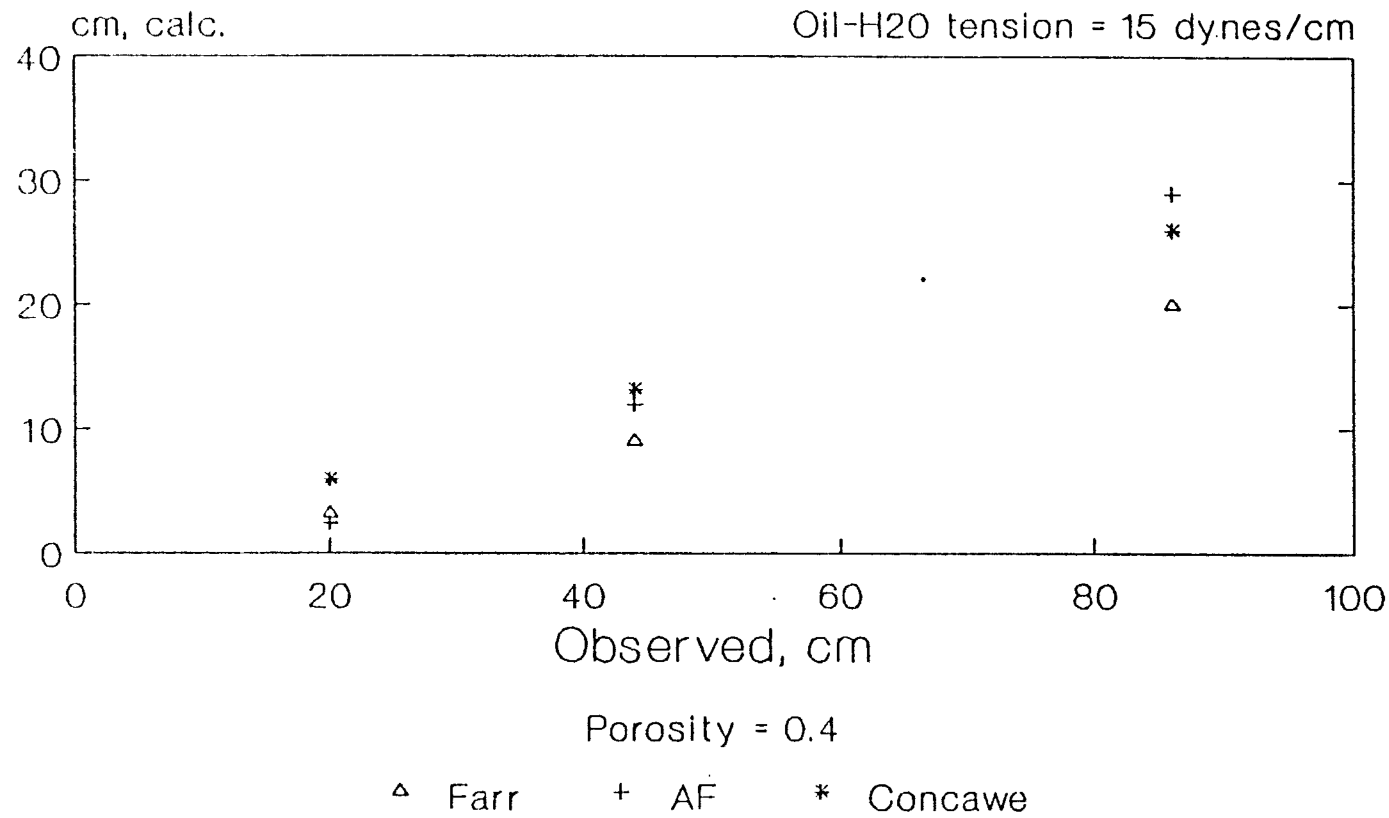


Figure 78. Columbus AFB SS-5 Well 42
Observed vs Calculated Thickness

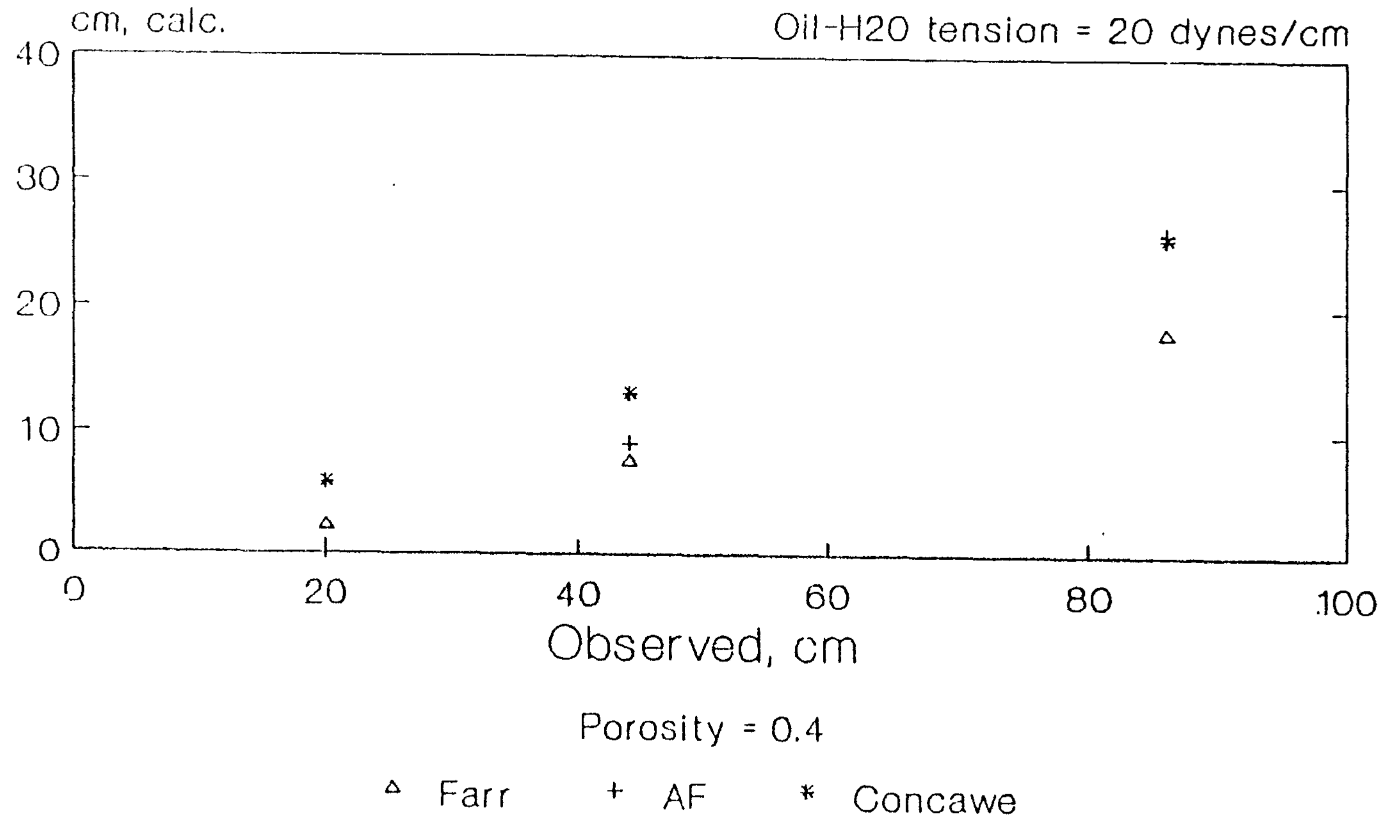


Figure 79. Columbus AFB SS-5 Well 42
Impact of Porosity (0.25) on Thickness

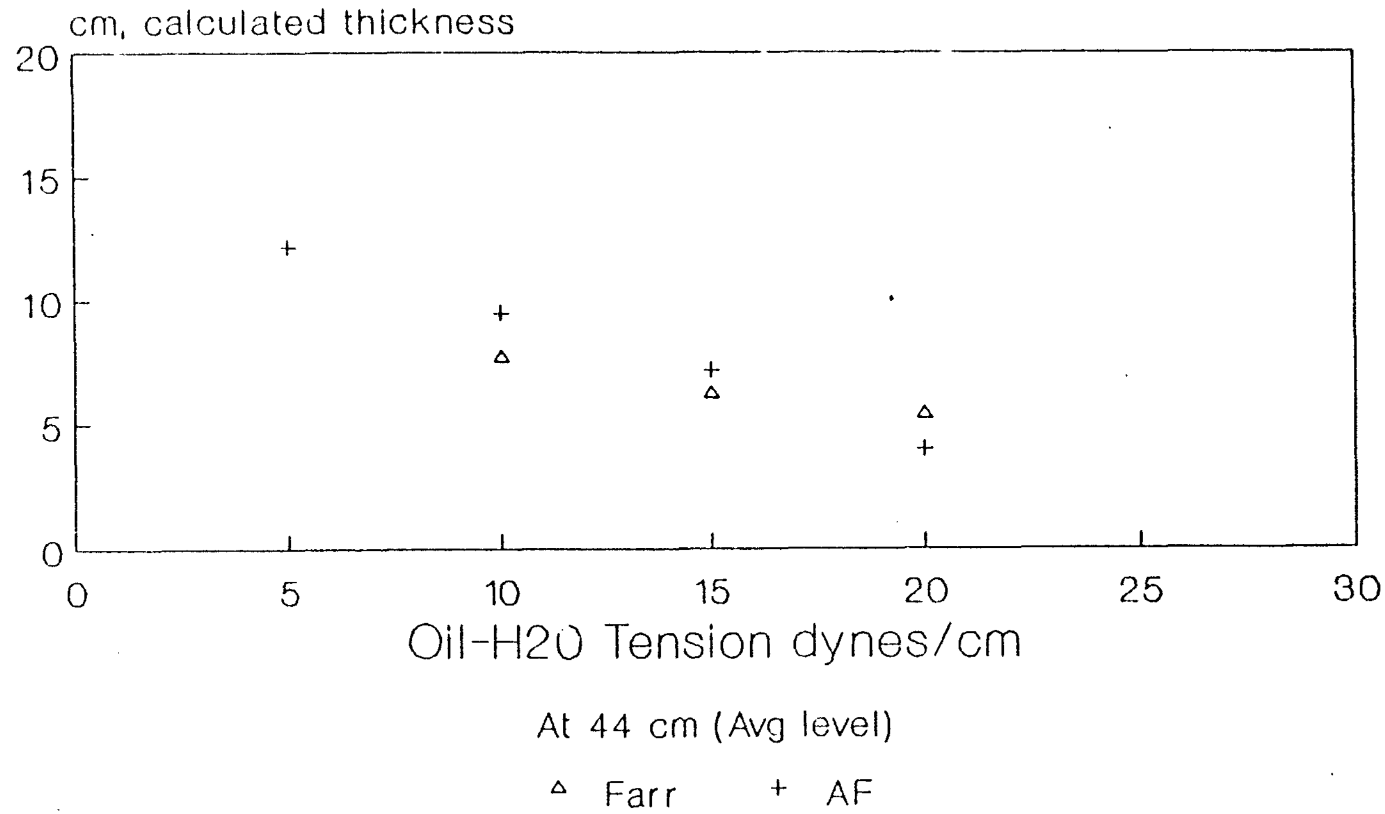


Figure 80. Columbus AFB SS-5 Well 42
Impact of Porosity (0.3) on Thickness

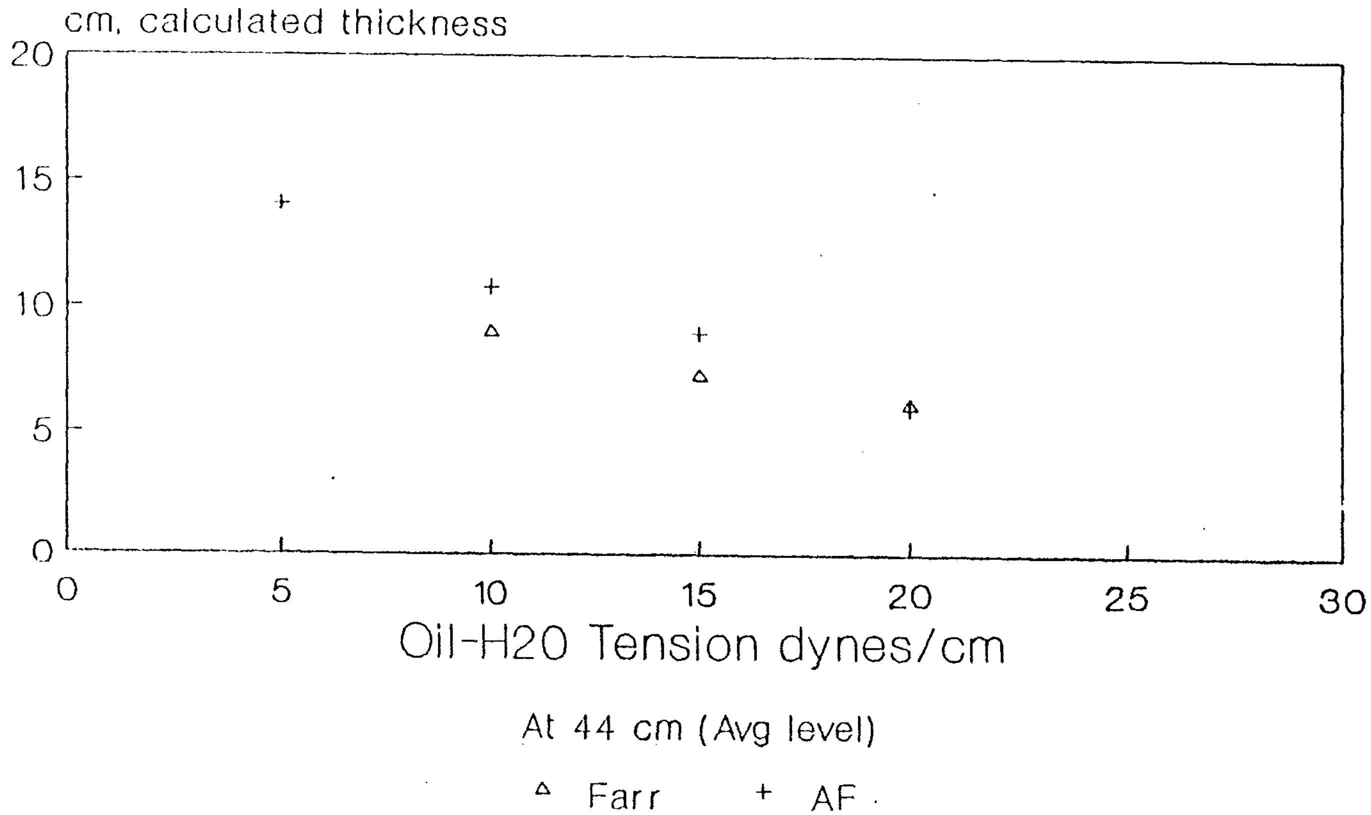


Figure 81. Columbus AFB SS-5 Well 42 Impact of Porosity (0.35) on Thickness

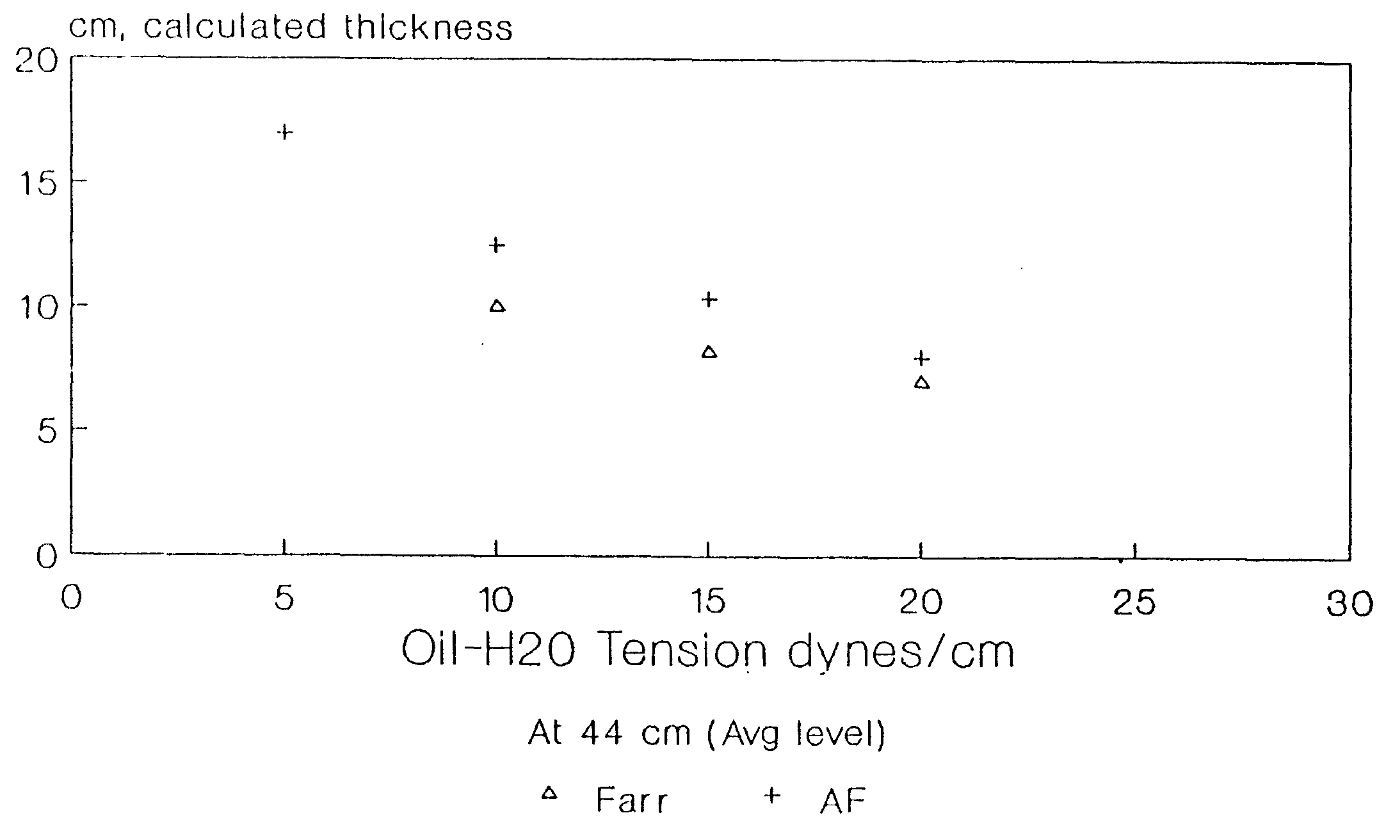


Figure 82. Columbus AFB SS-5 Well 42
Impact of Porosity (0.4) on Thickness

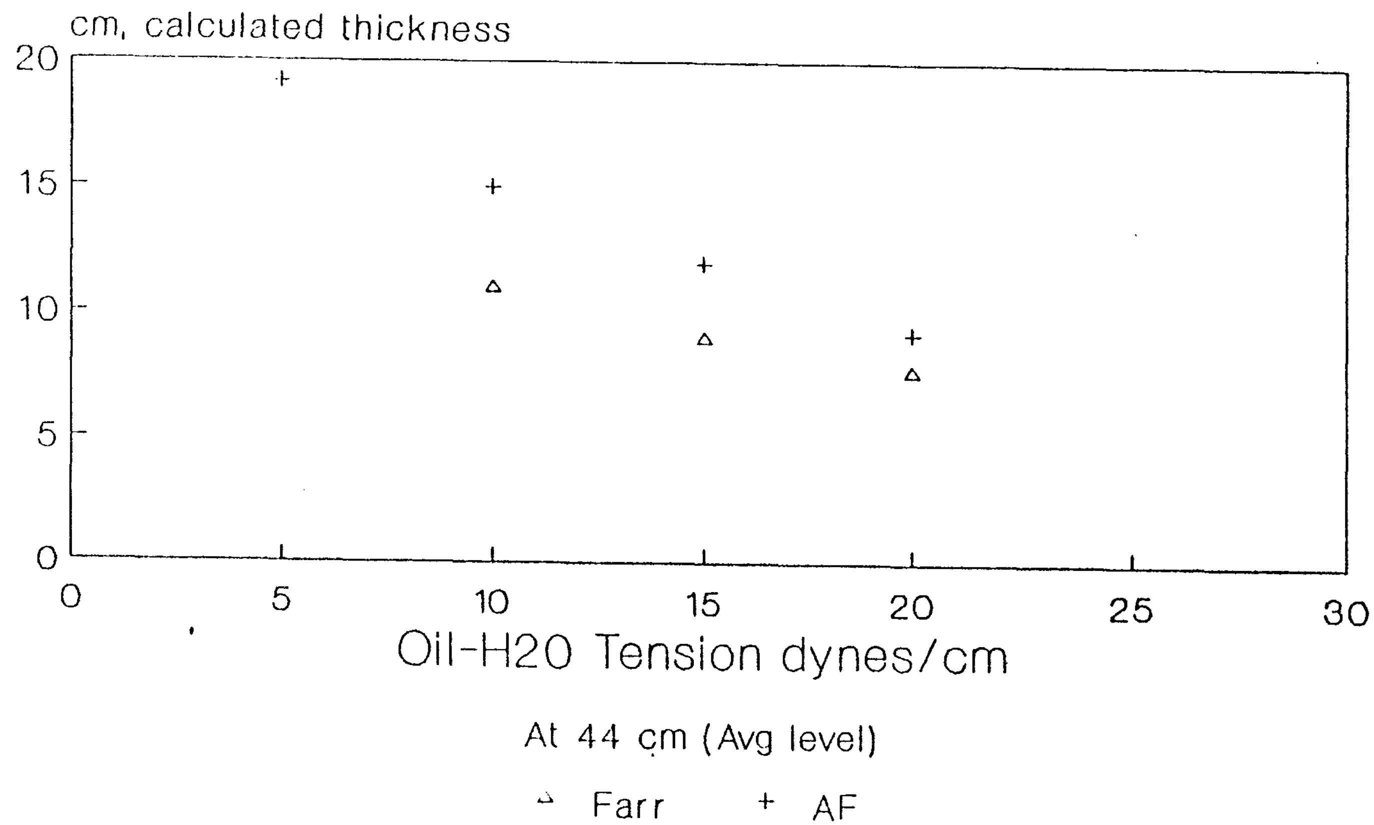
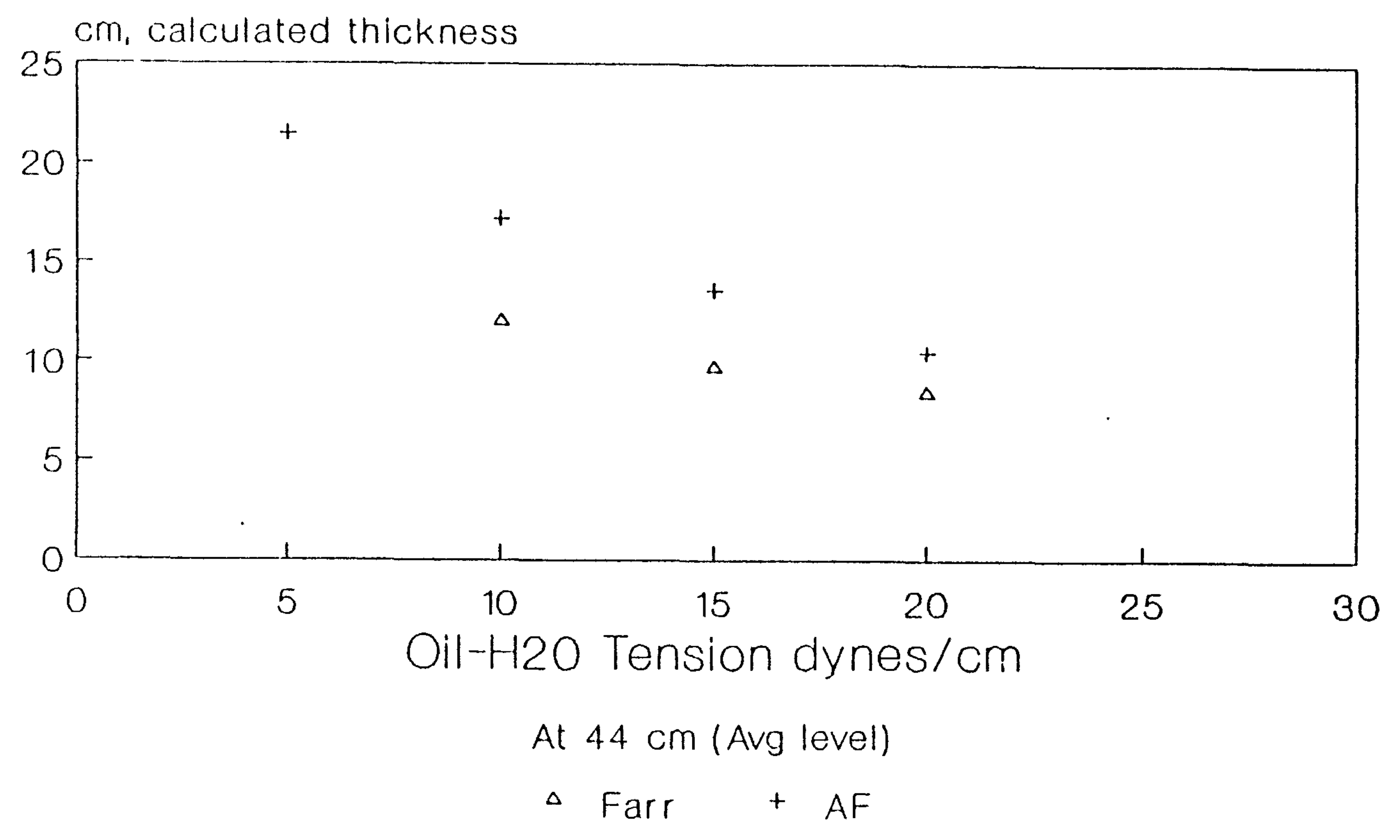


Figure 83. Columbus AFB SS-5 Well 42
Impact of Porosity (0.45) on Thickness



CONCLUSIONS

GEOLOGY

The geology of the majority of the sites in this study contained fine to coarse grained sands. As described in the methodology section, the inputs into SOILPROP were based on assigning particle size distributions (PSDs) by interpreting well logs or from PSDs done at or near the site of the JP-4 plume. Two of the six sites had PSDs available for input into SOILPROP, reducing the potential error of incorrect well log interpretations at these sites. It was noted that the geology a site as noted on two or more well logs could vary widely; both spatially and from different interpretations of the well core samples. This must be kept in mind when conducting fuel thickness calculations using the methods described in this report.

The ideal data for input into SOILPROP would be an actual PSD (using ASTM) from the well in question at the interfacial zone between fuel and water. Additional PSDs from nearby wells (with or without free product) at the zones of the highest and lowest level of the water table would enhance the SOILPROP inputs by providing data regarding the entire zone of vertical influence. This is especially critical in areas containing clay lenses.

The air-water displacement pressure (Pd^{aw}) head (hence the air organic displacement pressure (Pd^{ao}) and oil-water displacement pressure (Pd^{ow}) computed) was largely impacted by the percentage of fines in the zone of JP-4 - water interface. In areas where a large percentage of fines appeared i.e. Columbus AFB MS, the fuel fringe was much greater than at locations with fewer fines (Edwards and Shaw). This occurrence must be kept in perspective when estimating the volume of recoverable free product. One would not expect to recover as much free product from zones with a high percentage of fines due to the capillary action (high residual saturation values at the fuel-water interface.

POROSITY

The author only had available for SOILPROP input the true porosity (ϕ) from one of the six sites in this study. The baseline condition of ϕ = 0.4 was chosen from published data (USGS 1984) of similar soil classifications as the soils stated on the well logs furnished for this project. The accuracy of the calculated fuel thickness using the AF and Farr equations can be improved by knowing the ϕ within 5%. This point is shown by comparing the calculated fuel thickness versus oil-water surface tension (σ_{ow}) values at the Langley, Shaw and Columbus sites. The calculated fuel thickness differed from 3 to 10 cm depending on the site when ϕ

increased from 0.25 to 0.45.

Both the Farr and AF equations assume the saturation of fuel in the soil at the porosity level chosen equals 100%. This assumption may lead to over estimating the volume of the recoverable product. It is known that even under the best of circumstances not all of the calculated thickness of fuel is recoverable. The Farr equation uses the residual saturation of water (S_r) factor generated by SOILPROP to correct the computed fuel thickness. The AF equation does not provide a means for direct correction of the computed thickness. Milligan (1989) recommends multiplying the computed answer by 0.8 to correct for nonrecoverable fuel.

The Concawe equation does not include ϕ as an input parameter. For this reason, the Concawe equation may be attractive to use when ϕ is unknown. The calculated Concawe answers showed no consistency of being above or below the AF and Farr equation answers. However, the observation was made that at ϕ levels less than 0.3, the AF and Farr computed answers are generally less than the Concawe computed thickness.

OIL-WATER SURFACE TENSION (σ_{ow})

The exact σ_{ow} value of the JP-4 was not known at any site. The σ_{ow} for JP-4 decreases with increasing age of the fuel.

Milligan (1989) measured the JP-4 σ_{ow} of fuel taken from a well at Tyndall AFB FL and determined its value to be 5.3 dynes/cm, while fresh JP-4 had a value of 25 dynes/cm. In most instances the JP-4 found at the sites included in this study has been ageing for many years. Therefore, using a σ_{ow} value of approximately 5-15 dynes/cm would appear to be reasonable. To test this concept, at several sites the Farr and AF equations were calculated at 5, 10, 15, and 20 dynes/cm. Results are presented in the Shaw, Langley and Columbus sections. The highest calculated JP-4 thicknesses in all cases were found at 5 dynes/cm. Through trial and error it was found the Farr equation is not sensitive in handling σ_{ow} values under 8 dynes/cm.

Comparison of the AF and Farr answers at the 10 dynes/cm level generally shows less than a 30% difference in calculated JP-4 thickness. The differences in the two computed answers is less at lower porosities (0.25 -0.35) and greater at the 0.4 to 0.45 porosity level. Differences of JP-4 thickness at the average observed thickness level (porosity = 0.4) between 5 and 20 dynes/cm ranged from 50 to 200%.

It is recommended the fuel found in monitoring wells be tested for density to be used in the Concawe equation and surface tension for use in the AF and Farr equations. Knowing the σ_{ow} value within 2-3 dynes/cm would enable those calculating the

thickness to arrive at the best possible answer based on our current state of knowledge.

OTHER THICKNESS MEASUREMENT FACTORS

As stated in all six separate conclusion sections of this study, relying on one or two fuel thickness measurements (disregarding the number of wells measured) to depict site conditions may result in calculating actual fuel thickness levels in error by a factor of 20. The variability in measured fuel thickness accounted for the largest difference between the calculated answers, regardless of equations utilized. This is due to the large differences seen between low and high observed thicknesses at the six sites. Very few of the 21 wells in this study could be described as static, that is, observed fuel levels relatively constant over time.

In addition, it was made clear that relying on the measured thickness from only one monitoring well in estimating the actual site product thickness may lead to widely varying conclusions. The point is the fuel thickness in a single well may not be indicative of the entire plume due to geologic or well construction features. Fortunately, most sites in this study had multiple monitoring wells containing free product from which a site JP-4 thickness average could be computed. However, if the average thickness between wells varies

greatly, the computed site average thickness may not be a reliable indicator for volume estimation. The rule of thumb for this point is: as the number of measurements from multiple wells increases, the greater will be the reliability of the estimated actual site product thickness. This point must be considered if free product only appears in a single well, and measurements of that well are used for site characterization.

It has been recommended that using the average observed fuel thickness readings obtained over a period of one year (n > 30) may be the best estimator of the true observed fuel thickness (Gilbert, 1987). The observed low and high readings were included to show the extreme answers possible when fuel thicknesses are based on one reading.

Very large differences were seen in observed fuel thickness levels, without corresponding changes in the depth to water table levels. This phenomena should be pursued through other research efforts in an attempt to characterize floating layers over time: What makes the fuel levels change? What is the relationship between observed fuel thickness and water table elevation, if any?

EQUATION COMPARISONS

As stated above, values generated by the Farr and AF equations are within 50% across all porosities and σ_{ow} values. Due to the number of unknown values for input parameters in the Farr and AF equations, the certainty of computing the actual JP-4 thickness at any given site is low. This is based on the lack of required information, i.e. particle size distributions, porosity, and actual fuel-water surface tension.

In this study, it was observed that the Farr equation is only effective at σ_{ow} levels greater than 8 dynes/cm. The AF equation will yield negative calculated thicknesses in some soil types at observed thickness levels up to 15 cm.

SOILPROP was useful in computing the Pd^{ow} and Pd^{ao} from computed Pd^{aw} values found through particle size distribution (PSD) interpretation. Again, if on-site PSD data is known, a SOILPROP output will be made, furnishing the lambda and S_r values required in the AF and Farr equations.

If the required data for the AF and Farr equations are unavailable, the author recommends using the Concawe equation for a good first estimate of the actual fuel thickness in soil. The difference between answers from Concawe compared

to Farr and AF differed by as much as 100%, however if the Concawe calculation is based on the average of many observations of fuel thickness, the answer should be reasonable. The Concawe equation is much simpler than either the Farr or AF equations, and based on the data in this study, yields an answer that is reasonable as well. If those conducting the fuel level measurements wish to "fine-tune" the Concawe answer, it can be done with the Farr or AF equations, with additional costs for particle size distributions (PSD), porosity testing, and measurement of oil-water surface tension (σ_{ow}) values. If the PSD or σ_{ow} values are known for a given site, it may be beneficial to calculate the estimated fuel thickness using the alternate equations and compare the answers to Concawe. This would enable those conducting the estimated thickness to put upper and lower limits on the computed answer by changing porosity and oil-water surface tension (σ_{ow}) to reflect best and worse case scenarios, i.e. high porosity, low σ_{ow} values. Putting boundaries on the product thickness estimate would be beneficial in designing remedial action technologies and ascertaining costs.

For the majority of the locations included in this study, simply applying the Concawe equation would give an answer accurate enough for the intended purpose; that is the design

of a JP-4 handling system, recovery well placement and design, and providing the regulators a recognized number so that remedial action can proceed.

REFERENCES

1. CONCAWE, Protection of Groundwater from Oil Pollution, Concawe Report No. 3/79, The Hague, 1979.

2. Van Dam, J., "The Migration of Hydrocarbons in a Water-Bearing Stratum In: The Joint Problems of the Oil and Water Industries," by Hepple, P., Ed., proc. Symposium held at Brighton Jan 18-20, 1967, The Institute of Petroleum TD 427.

3. Zilliox, L., "Effect of Hydrodynamic Processes on the Development of Groundwater Pollution," Progress in Water Technology, 7: (3/4) 561-568, 1975.

4. Farmer, V. E., "Behavior of Petroleum Contamination in an Underground Environment," Proceedings of the Ground Water and Petroleum Hydrocarbons Protection, Detection, and Restoration, PACE, Toronto, Ontario, 1983.

5. Yaniga, P. M., "Hydrocarbon Retrieval and Apparent Hydrocarbon Thickness: Interralationships to Recharging/ Discharging Aquifer Conditions," Petroleum Hydrocarbons and Organic Chemicals in Ground Water - Prevention, Detection, and Restoration, Houston TX, 1984.

6. Yaniga, P. M., and Warburton, J. G., "Discrimination Between Real and Apparent Accumulation of Immiscible Hydrocarbons on the Water Table: A Theoretical and Empirical Analysis," Fourth National Symposium and Exposition of Aquifer Restoration and Ground Water Monitoring. Columbus, Ohio, 1984.

7. Blake, S. B., and Hall, R. A., "Monitoring Petroleum Spills with Wells: Some Problems and Solutions," Fourth National Symposium and Exposition on Aquifer Restoration and Ground Water Monitoring, Columbus Ohio, 1984.

8. Schiegg, H. O., "Considerations of Water, Oil, and Air in Porous Media," Water Science and Technology, 17: 467-476, 1984.

9. Hampton, D. R., "Laboratory Investigations of the Relationship Between Actual and Apparent Product Thickness in Sands," Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Restoration, Houston, Texas, 1988.

10. Farr, A. M., Houghtalen R. J., and McWhorter, D. B., "Volume Estimation of Light Nonaqueous Phase Liquids in Porous Media," Groundwater, 28: 48-56, 1990.

11. Corey, A. T., Mechanics of Immiscible Fluids in Porous Media. Water Resources Publications, Littleton, Colorado, 1986.

12. van Genuchten, M., "A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils," Soil Science Society of America Journal, 44: 892-898, 1980.

13. Hampton, D. R., "Laboratory Investigation of the Relationship Between Actual and Apparent Product Thickness in Sands" Proceedings of the American Association of Petroleum Geologists: Environmental Concerns in the Petroleum Industry, Palm Springs CA May 10-12, 1989

14. Milligan, J. D., and Durnford, D., "Petroleum Thickness in Groundwater - A Laboratory Study," US Air Force Engineering and Services Center Draft Report ESL-TR-89-53, March 1989.

15. Lenhard, R. J., and Parker, J. C., "Estimation of Free Hydrocarbon Volume from Fluid Levels in Monitoring Wells," Groundwater, 28: 57-67, 1990.

16. Heath, R. C., Basic Ground-Water Hydrology, U.S. Geological Survey (USGS) Water-Supply Paper 2220, U.S. Government Printing Office, 1984.

17. Macewen, T. E., "Toxic Hazards Research Unit Annual Technical Report: 1984, Hydrazine, JP-4 and JP-8," Air Force Aerospace Medical Research Laboratory (AMARL) Report TR-84-001, 1985.

18. Dismukes J. W., and Hunt, T. P., "Toxic Effects of Petroleum and Shale JP-4 and JP-8 Aviation Fuels on Fathead Minnows", Water Resources Bulletin. 21: 49-51, 1985.

19. Fisher, J. T., and Eurell, T. P., "A Study Regarding the Association of Alpha-2U Globulin with the Nephrotoxic Mechanism of Certain Petroleum-Based Air Force Fuels", Air Force Office of Scientific Research (AFOSR) Report TR-86-2177, 1986.

20. Mishra, S., and Parker, J. C., "Estimates of Soil Hydraulic Properties and their Uncertainty from Particle Size Distribution Data." Journal of Hydrology (In Press), 1989.

21. Gilbert, R. O., Statistical Methods For Environmental Pollution Monitoring. Van Nostrand Reinhold, New York, 1987.

22. US Air Force Installation Restoration Program Report IRP-602-5, Shaw AFB SC, 1988.

23. US Air Force Installation Restoration Program Report IRP-12B-97385C, Homestead AFB FL, 1988.

24. US Air Force Installation Restoration Program Report IRP-11-0546, Langley AFB VA, Site 4, 1989.

25. US Air Force Installation Restoration Program Report IRP-409659, Williams AFB AZ, 1989.

26. US Air Force Installation Restoration Program Report IRP-PE064.03, Edwards AFB CA, Site 17, 1986.

27. US Air Force Installation Restoration Program Report IRP-MGM22751.50.07, Columbus AFB MS, 1989.

28. Oil Recovery Systems (ORS) Operations Manual, Interface Probe, Environmental Equipment, Greenville, NH, 1988.

APPENDIX A

SHAW AFB SC

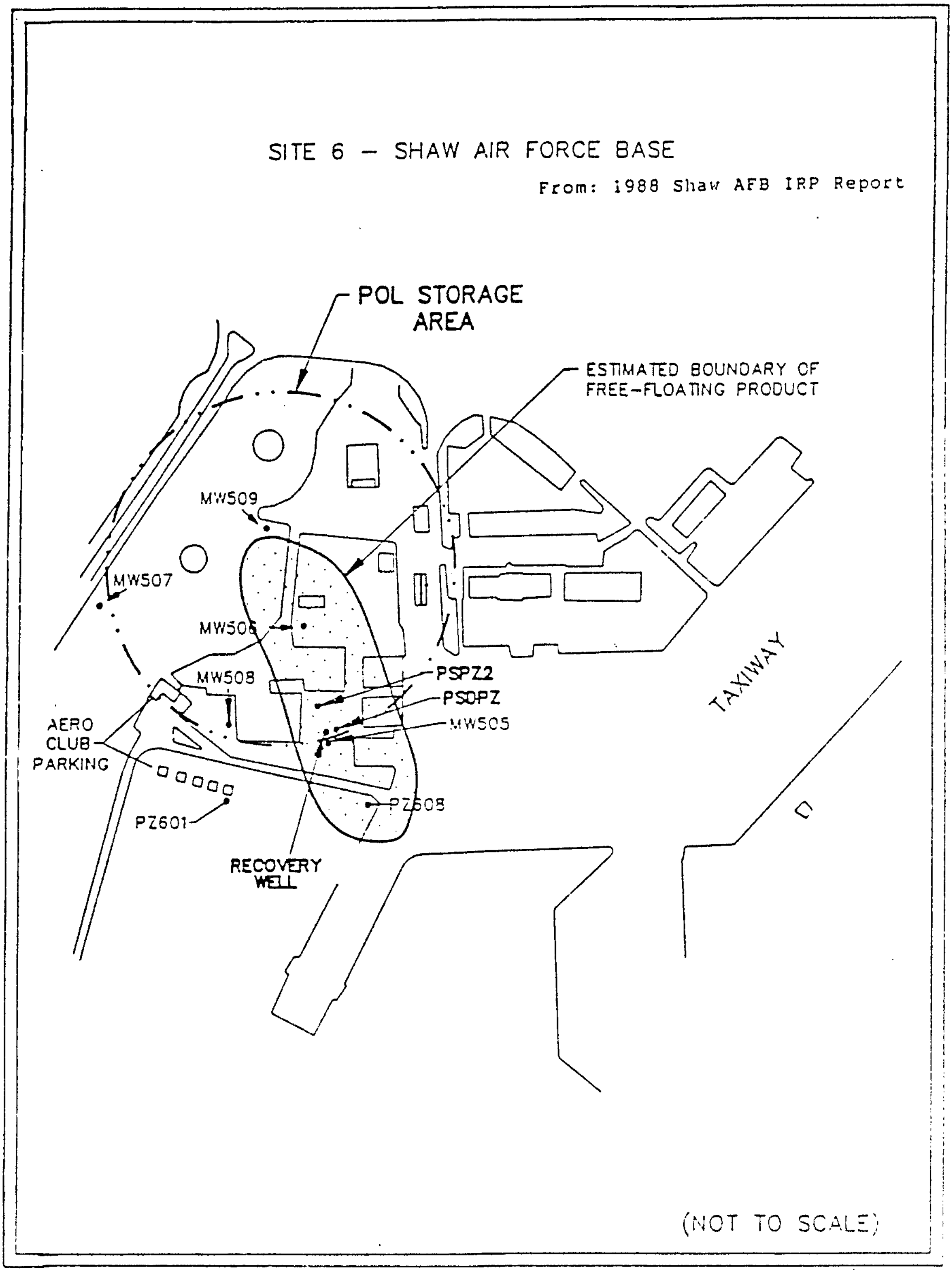


FIGURE A-1
LOCATION OF RECOVERY WELL SYSTEM - SHAW

From: 1988 Shaw AFB IRP Report

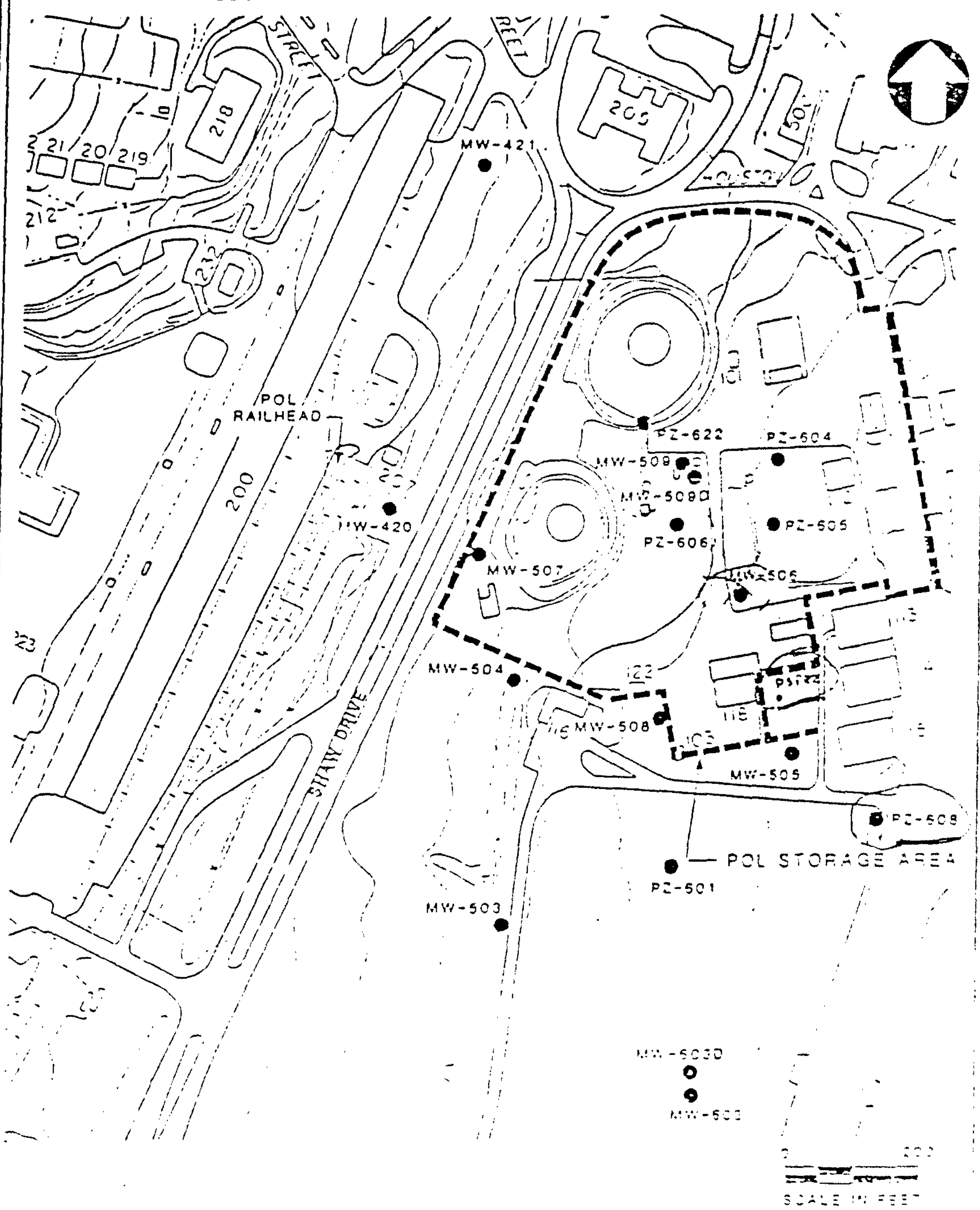


FIGURE A-2
POL STORAGE LOCATION - SHAW

TABLE A-1. OBSERVED FUEL THICKNESS READINGS, SHAW AFB SC, 1989

1989	Well PZ 608 Fuel Thickness cm	Well PSPZ2 Fuel Thickness cm	Well MW 505 Fuel Thickness cm	Well PZ 601 A Fuel Thickness cm	Well PZ606 Fuel Thickness cm
9 March	61.6	50.2	47.0	not monitored	not monitored
16 March	62.7	51.5	47.2	(nm)	(nm)
24 March	64.0	51.8	47.2	(nm)	(nm)
30 March	61.0	51.2	45.7	(nm)	(nm)
6 April	61.8	53.3	49.4	(nm)	(nm)
20 April	63.7	53.4	50.2	27.4	73.7
27 April	61.0	53.4	45.8	(nm)	(nm)
4 May	58.2	51.2	43.9	26.5	68.8
11 May	58.0	49.4	40.5	(nm)	(nm)
19 May	57.3	45.7	39.6	11.6	62.5
25 May	58.0	48.1	38.7	25.6	62.2
2 June	58.0	48.1	35.0	24.4	61.0
8 June	58.0	48.1	35.0	23.5	61.0
15 June	58.0	47.8	33.8	23.5	59.4
23 June	61.0	48.7	27.4	22.2	59.2
20 July	59.1	50.6	24.7	19.8	56.7
3 August	59.1	51.5	26.0	19.2	58.5
11 August	59.1	51.8	26.0	22.8	59.1
17 August	59.0	50.3	24.1	21.3	58.2
29 August	57.3	not monitored	46.3	24.4	57.0
31 August	58.1	(nm)	49.4	26.8	56.1
7 Sept	54.8	48.7	28.9	37.2	51.8
10 Oct	61.0	56.4	35.0	37.5	51.8
26 Oct	45.7	58.8	35.0	44.5	47.8
9 Nov	34.2	(nm)	55.2	53.9	47.2
16 Nov	30.5	42.7	55.0	57.3	(nm)
7 December	27.4	55.0	(nm)	27.4	45.7
21 Dec	23.5	55.0	40.5	46.9	48.8
28 Dec	28.3	57.3	39.6	42.7	57.3

TABLE A-2. OBSERVED FUEL THICKNESS READINGS, SHAW AFB SC, 1990

Shaw AFB SC	Well PZ 608 Fuel Thickness	Well PSPZ2 Fuel Thickness	Well MW 505 Fuel Thickness	Well PZ 6[illegible]1 A Fuel Thickness	Well PZ606 Fuel Thickness
1990	cm	cm	cm	cm	cm
4 January	24.4	58.2	39.6	42.0	48.7
18 Jan	42.7	54.8	39.5	39.8	47.2
25 Jan	64.6	52.7	39.6	33.5	42.7
1 Febuary	45.7	54.2	38.7	36.6	48.2
22 Feb	43.6	54.8	37.5	33.8	50.3
5 April	48.7	54.8	39.6	29.6	48.1
19 April	50.6	54.8	41.2	31.4	50.3
26 April	54.8	57.0	42.9	30.8	51.2
3 May	61.6	53.3	47.0	50.3	51.8
17 May	59.2	56.1	45.4	31.1	50.6
24 May	65.5	54.8	48.8	30.5	51.8
31 May	58.5	(nm)	49.4	(nm)	46.3
1 June	56.4	54.8	44.2	31.1	51.8
14 June	55.2	54.8	48.8	36.0	51.8
26 June	54.8	55.8	57.9	31.1	59.4
9 August	71.6	54.8	53.6	25.3	61.0
16 August	76.2	56.4	54.8	21.3	64.6
	Average	Average	Average	Average	Average
	54.2	52.7	41.8	31.6	54.7
	low	low	low	low	low
	23.5	42.7	24.1	11.6	42.7
	high	high	high	high	high
	76.2	58.8	55.2	57.3	73.7

TABLE A-3. OBSERVED DEPTH TO WATER READINGS, SHAW AFB SC, 1989

Shaw AFB SC 1989	Well PZ 608 Depth to Water cm	Well PSPZ2 Depth to Water cm	Well MW505 Depth to Water cm	Well PZ601 A Depth to Water cm	Well PZ606 Depth to Water cm
9 March	1457	1451	1460	not monitored	not monitored
16 March	1457	1454	1460	(nm)	(nm)
24 March	1466	1457	1463	(nm)	(nm)
30 March	1466	1460	1463	(nm)	(nm)
6 April	1472	1460	1469	(nm)	(nm)
20 April	1472	1460	1469	1521	1469
27 April	1463	1460	1463	(nm)	(nm)
4 May	1460	1460	1463	1515	1460
11 May	1460	1451	1457	(nm)	(nm)
19 May	1457	1444	1454	1493	1448
25 May	1451	1445	1448	1506	1445
2 June	(nm)	1440	1443	1500	1442
8 June	1448	1439	1440	1496	1440
15 June	1444	1435	1436	1493	1437
23 June	1445	1434	1430	1491	1434
20 July	1439	1430	1421	1484	1430
3 August	1435	1426	1418	1480	1424
11 August	1434	1426	1416	1483	1423
17 August	1431	1422	1412	1478	1421
29 August	1429	(nm)	1418	1479	1418
31 August	1426	(nm)	1418	1478	1417
7 September	1422	1417	1410	1485	1400
10 October	1416	1407	1403	1485	1400
26 October	1387	1394	1390	1460	1380
9 November	1366	(nm)	1384	1455	1368
16 November	1361	1384	1382	1452	1365
7 December	1400	1377	(nm)	1393	1362
21 December	1396	1373	1375	1438	1360
28 December	1402	1376	1375	1437	1360

TABLE A-4. OBSERVED DEPTH TO WATER READINGS, SHAW AFB SC, 1990

Shaw AFB SC 1990	Well PZ 608 Depth to Water cm	Well PSPZ2 Depth to Water cm	Well PZ606 Depth to Water cm	Well PZ601 A Depth to Water cm	Well MW 505 Depth to Water cm
4 January	1397	1375	1374	1434	1359
18 Jan	1380	1373	1375	1435	1360
25 Jan	1396	1372	1376	1399	1370
1 Feb	1380	1369	1371	1428	1356
22 Feb	1377	1365	1366	1420	1353
5 April	1379	1367	1368	1410	1354
19 April	1384	1371	1375	1428	1359
26 April	1387	1368	1373	1425	1357
3 May	1425	1400	1430	1420	1420
17 May	1395	1376	1380	1431	1363
24 May	1381	1372	1368	1423	1356
31 May	1400	(nm)	1388	(nm)	1362
1 June	1400	1387	1370	1428	1364
14 June	1395	1390	1384	1429	1387
26 June	1396	1395	1405	1433	1408
9 August	1429	1397	1408	1452	1395
16 August	1436	1400	1411	1452	1397
	Average	Average	Average	Average	Average
	1420	1411	1412	1457	1395

Figure A-3. Shaw AFB SC Well MW505 JP-4 Thickness & H20 table depths

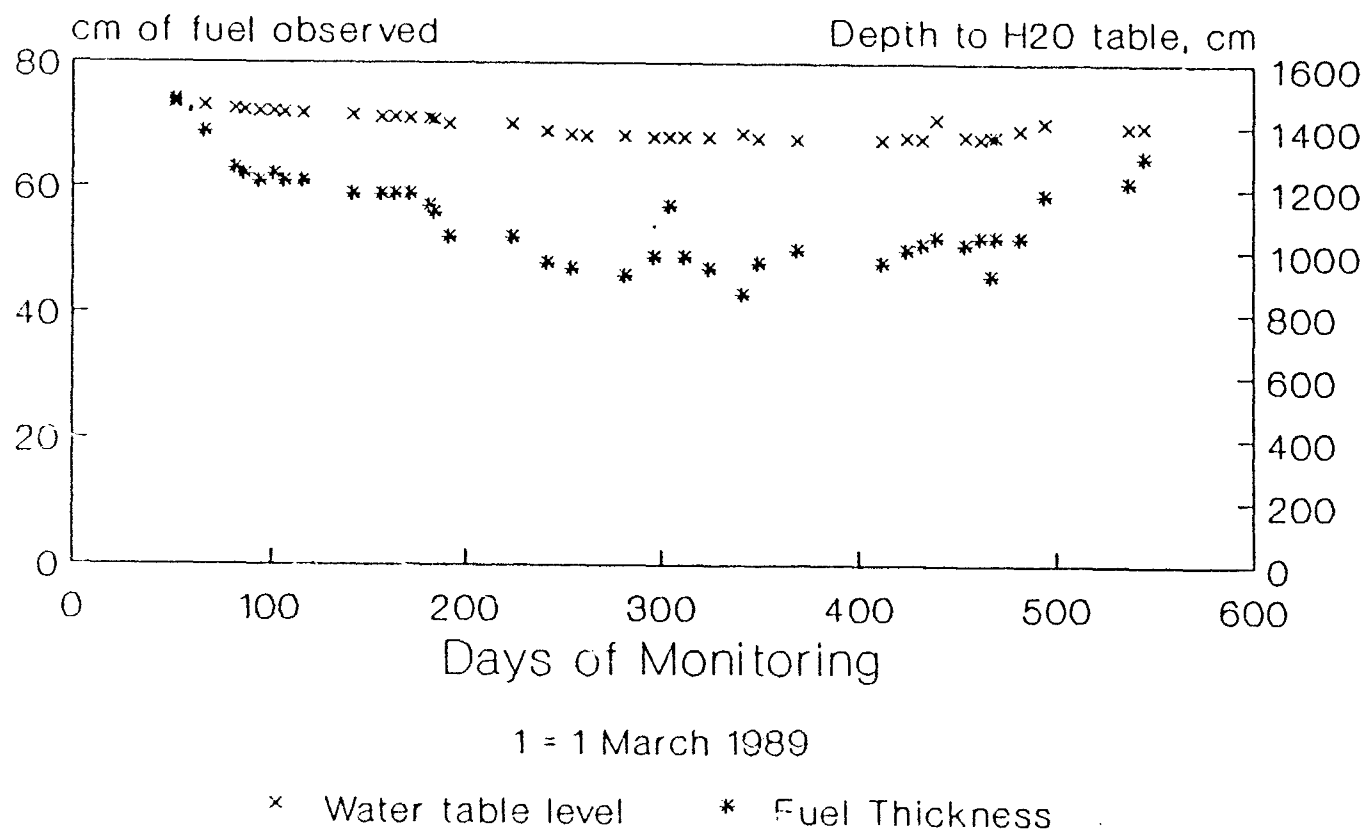


Figure A-4. Shaw AFB SC Well PZ601 A JP-4 Thickness & H20 table depths

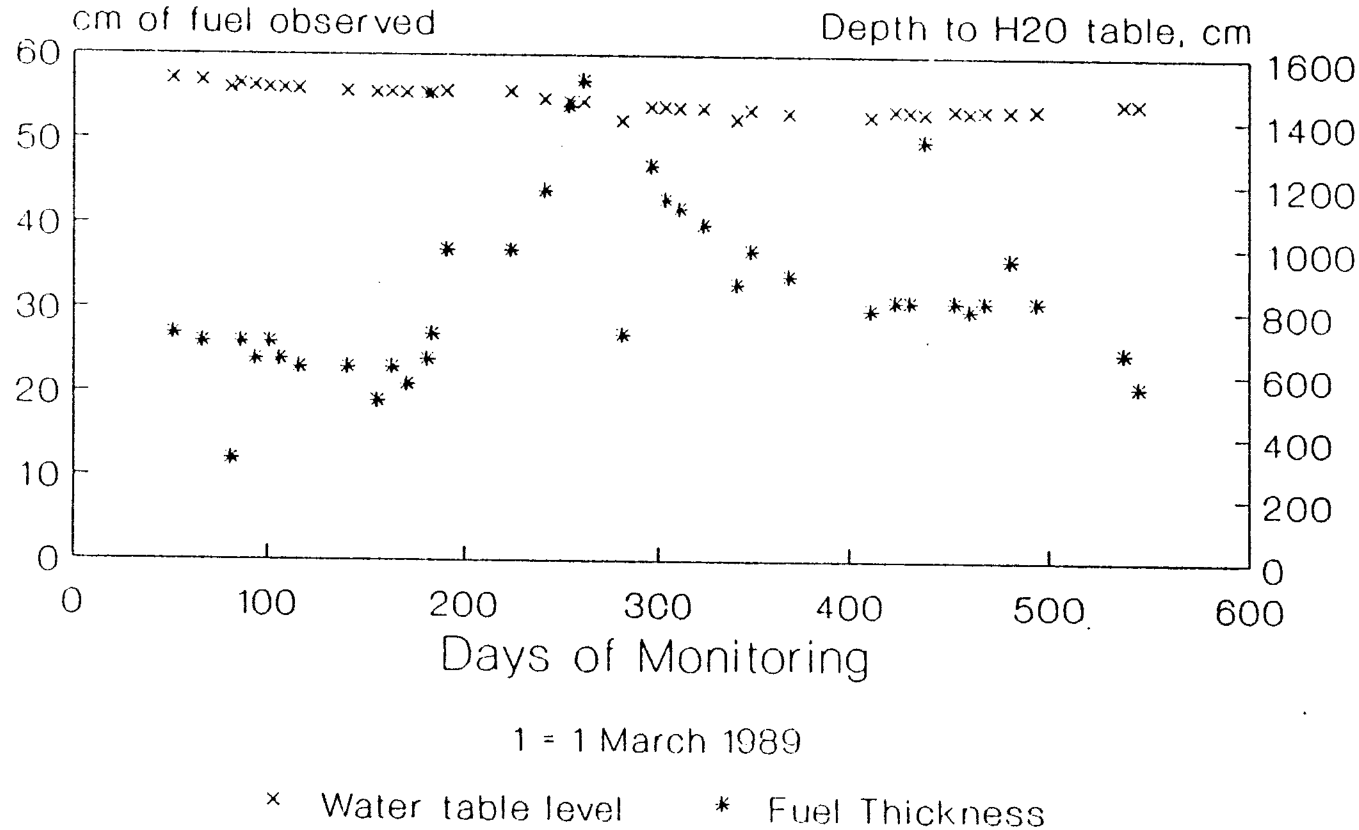


Figure A-5. Shaw AFB SC Well PZ608
Fuel Thickness & H20 table depths

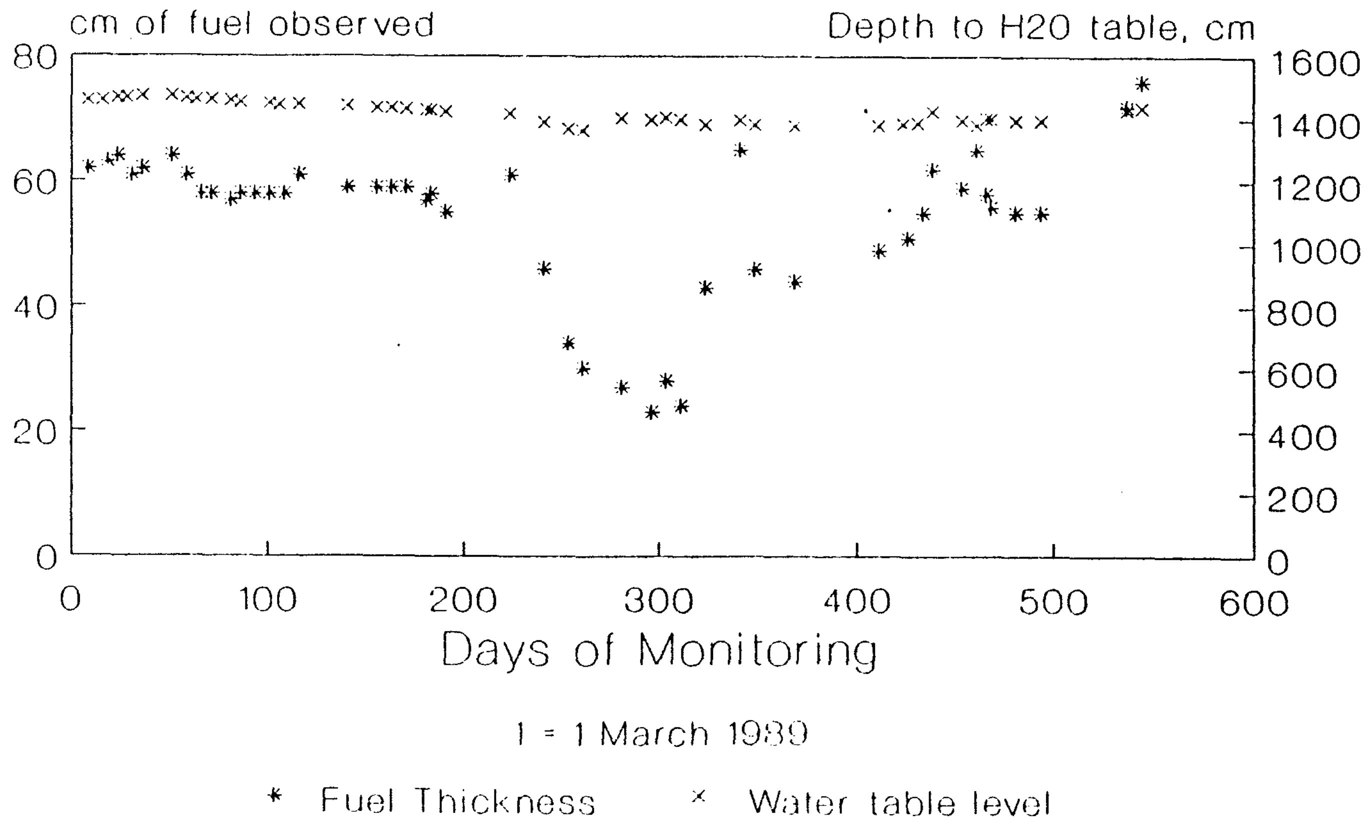


Figure A-6. Shaw AFB SC Well PSPZ2
Fuel Thickness & H20 table depths

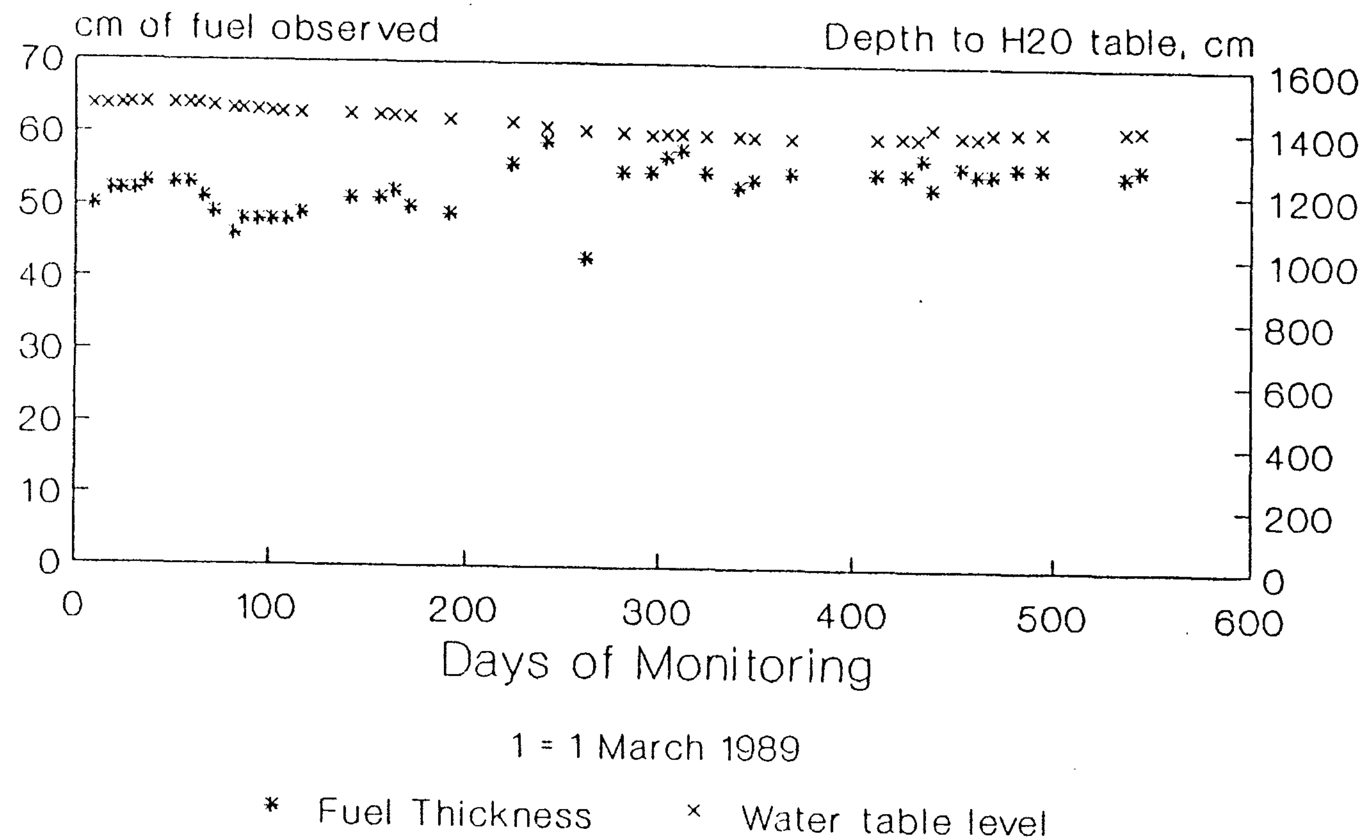
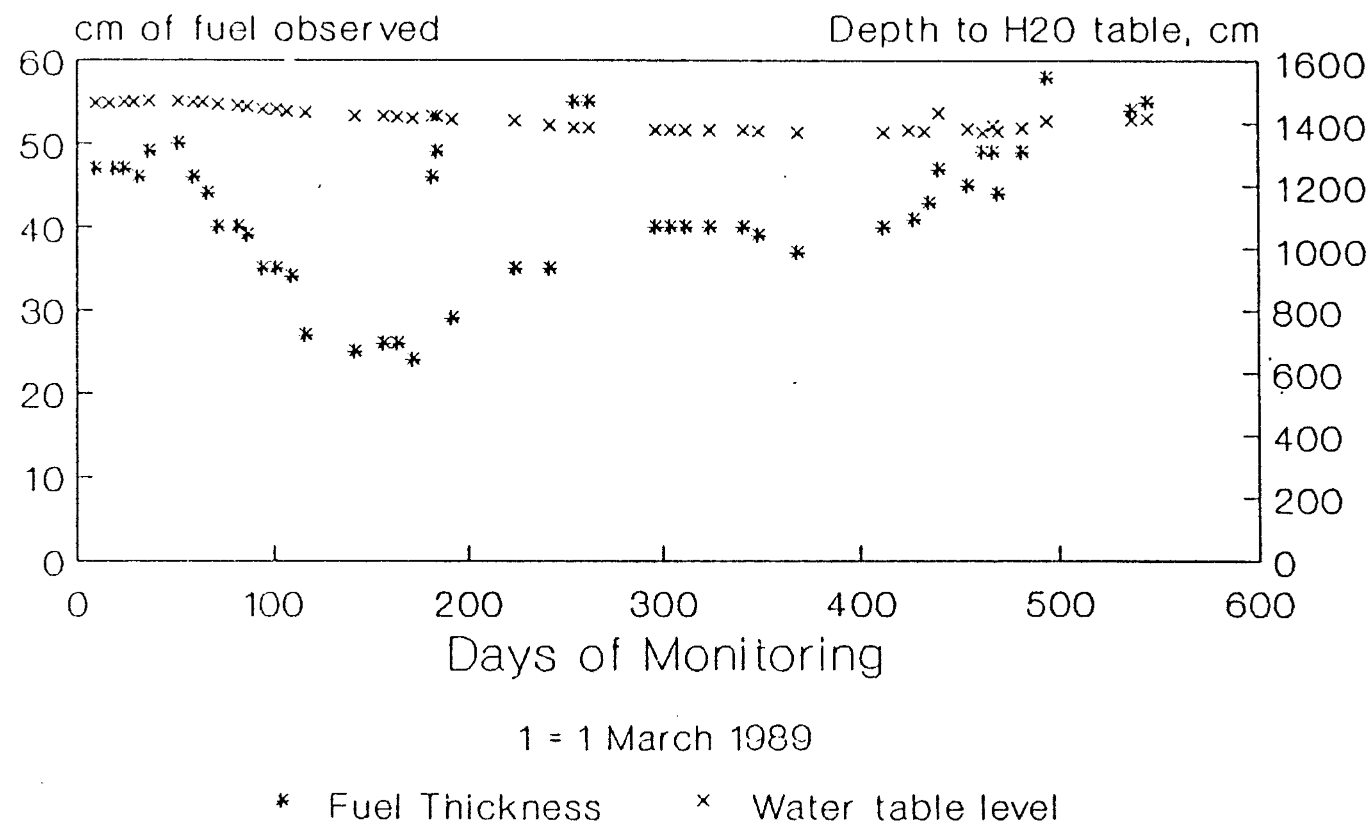


Figure A-7. Shaw AFB SC Well PZ606 Fuel Thickness & H20 table depths



From: 1988 Shaw AFB IRP Report

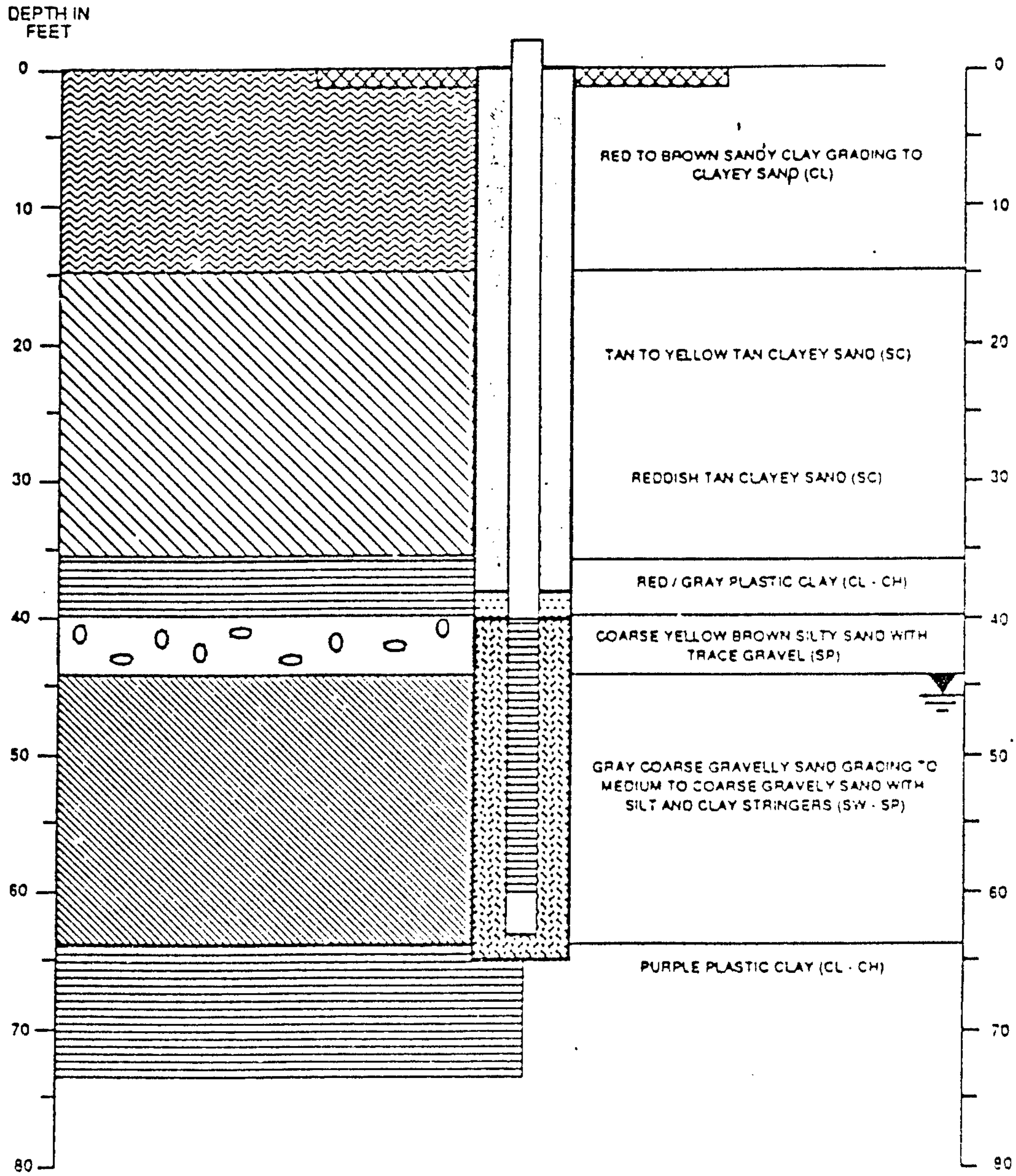


FIGURE A-8
PIEZOMETER PSPZ2 LOG - SHAW

From: 1988 Shaw AFB IRP Report

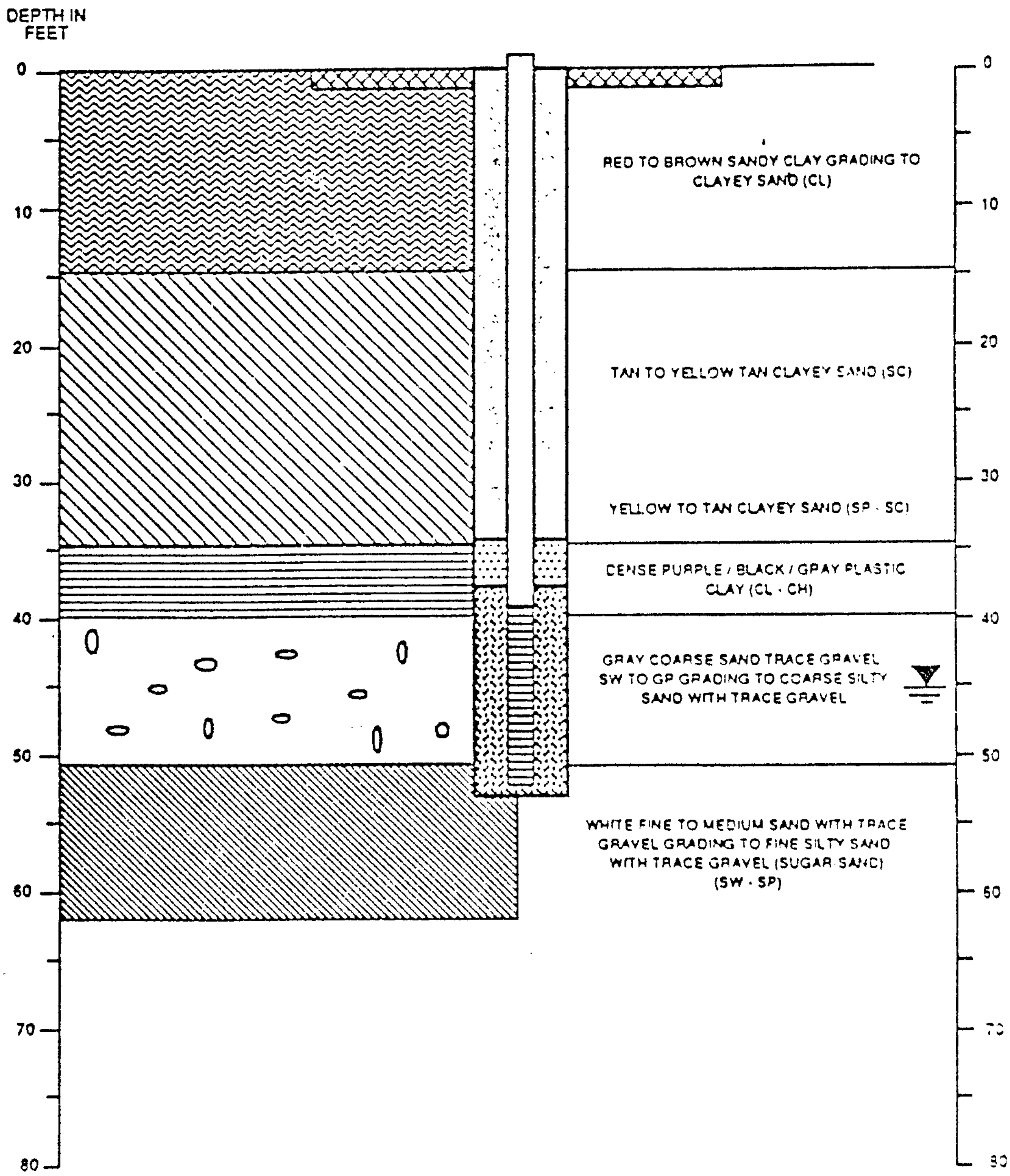


FIGURE A-9
MONITORING WELL MW505 LOG

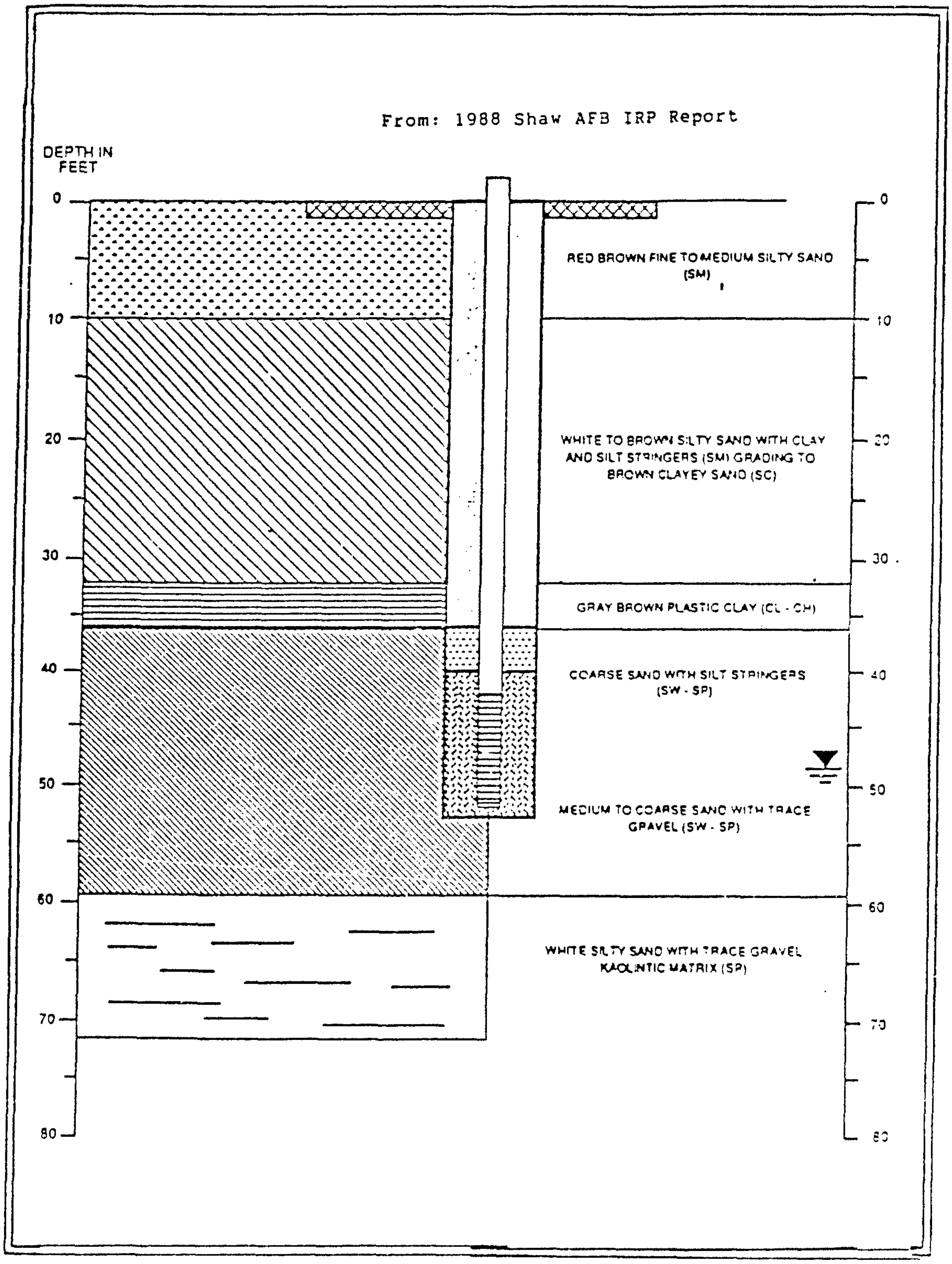
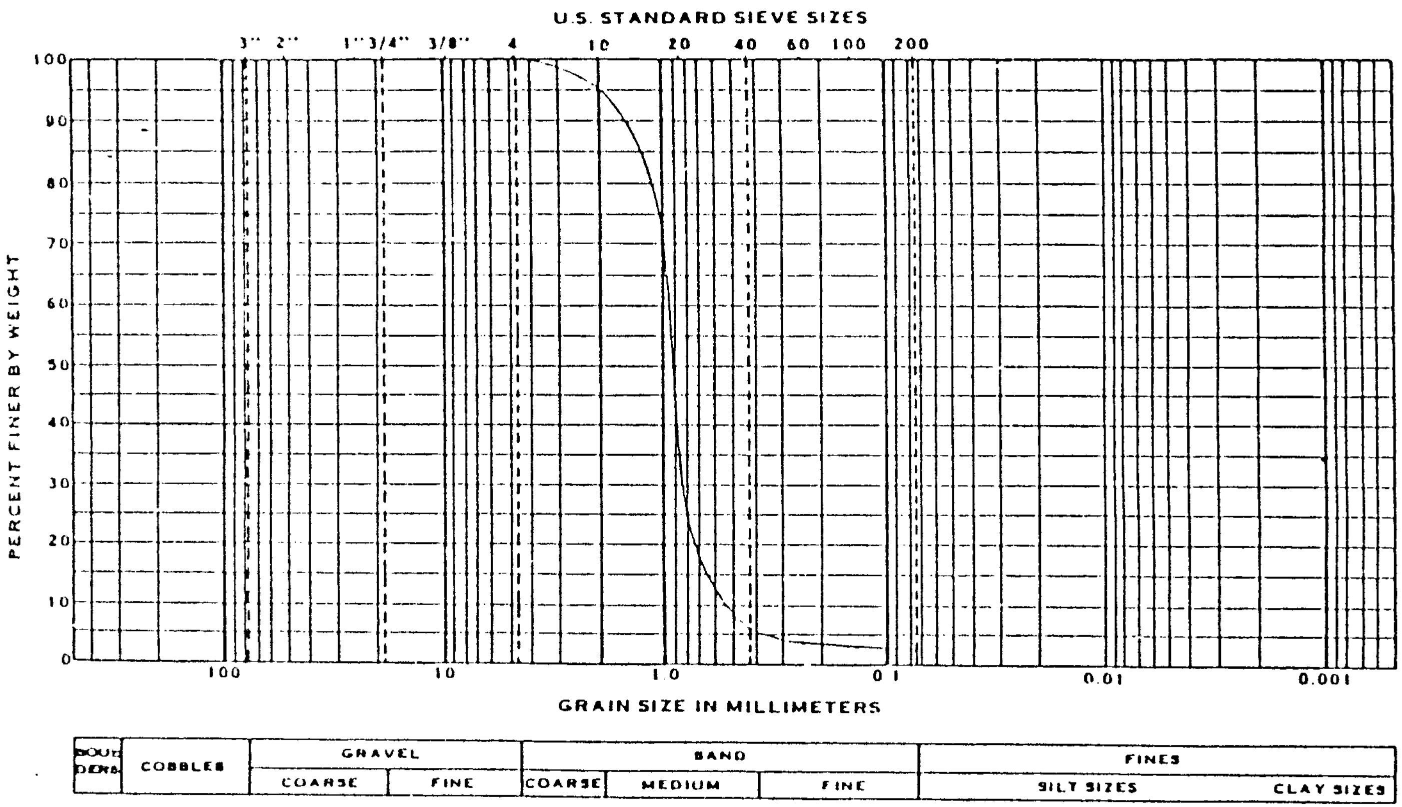


FIGURE A-10
PIEZOMETER PZ601 LOG

TO:
DATE SUBMITTED: 2/15/89
From: 1988 Shaw IRP Rpt REVIEWED BY: (CTotAL)



BORING NO	ELEV OR DEPTH	NAT WC	LL	PL	PI	DESCRIPTION OR CLASSIFICATION
REC WELL	52 - 53'					

GRAIN SIZE DISTRIBUTION
JOB NO. 11-8528.01 DATE 2/15/89
LAB NO. 9105

FIGURE A-11
PARTICLE SIZE DISTRIBUTION - SHAW

From: 1988 Shaw AFB IRP Report

LEGEND

```
                        S DRY WT= 100.00              — CUMULATIVE WT. RETAINED
SIEVE NO/SIZE ———→ 10|00     0.00 100.0  ←———— PERCENT PASSING/FINER
                    20|00     0.50  99.5
                    40|00     4.00  96.0
                    60|00    20.00  80.0
                   100|00    46.00  54.0
                   200.00    52.00  48.0
                   HYDRM DRY WT=  50.00
                   SPECF GRAV=   2.68
TEMPERATURE        NUMBER=  76.00
                   DISPAGT=   6.50               — HYDROMETER READING
ELAPSED TIME (MIN.) ——— 2 20.2 25.0
                     0.03405             34.8 ←—— PERCENT PASSING/FINER
PARTICLE DIAMETER (MM)  5 20.2 24.0
                     0.02167             33.0
                    15 20.2 23.0
                     0.01259             31.2
                    30 20.2 21.0
                     0.00901             27.7
                    60 20.4 18.0
                     0.00647             22.5
                   120 20.6 17.0
                     0.00459             20.7
                   240 20.6 16.0
                     0.00326             18.9
                  1440 20.0 15.0
                     0.00135             16.9
```

DATA

```
LAB #: 9105
S DRY WT= 213.10
# 4------      0.00 100.0
# 10-----      9.13  95.8
# 20-----    145.75  33.2
# 40-----    205.15   5.3
# 60-----    210.13   3.7
# 100----    211.74   2.3
# 200----    212.41   2.4
```

FIGURE A-11
PARTICLE SIZE DISTRIBUTION (CONTINUED)

APPENDIX B

HOMESTEAD AFB FL

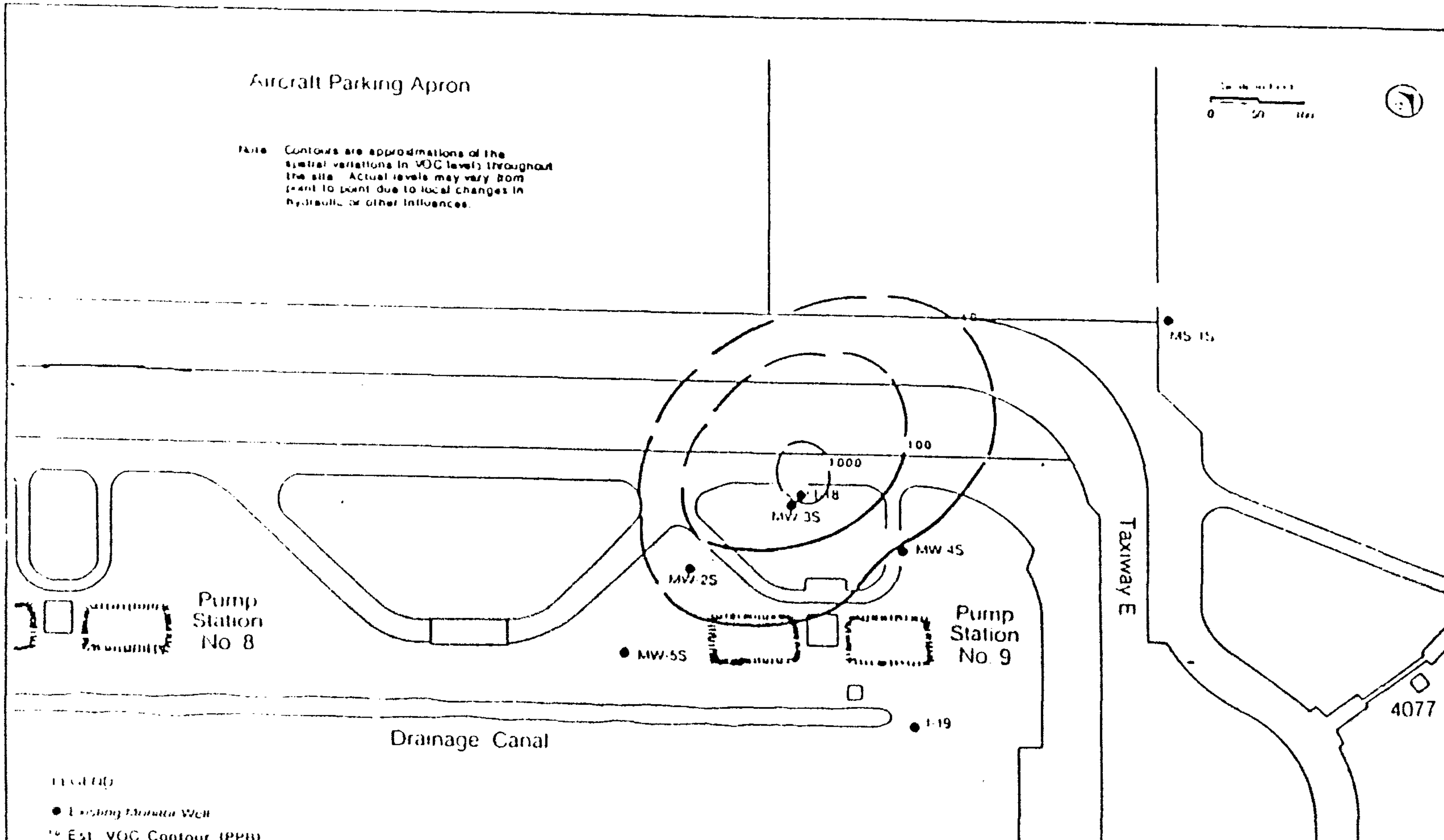


FIGURE B-1
HOMESTEAD AFB SITE 9.

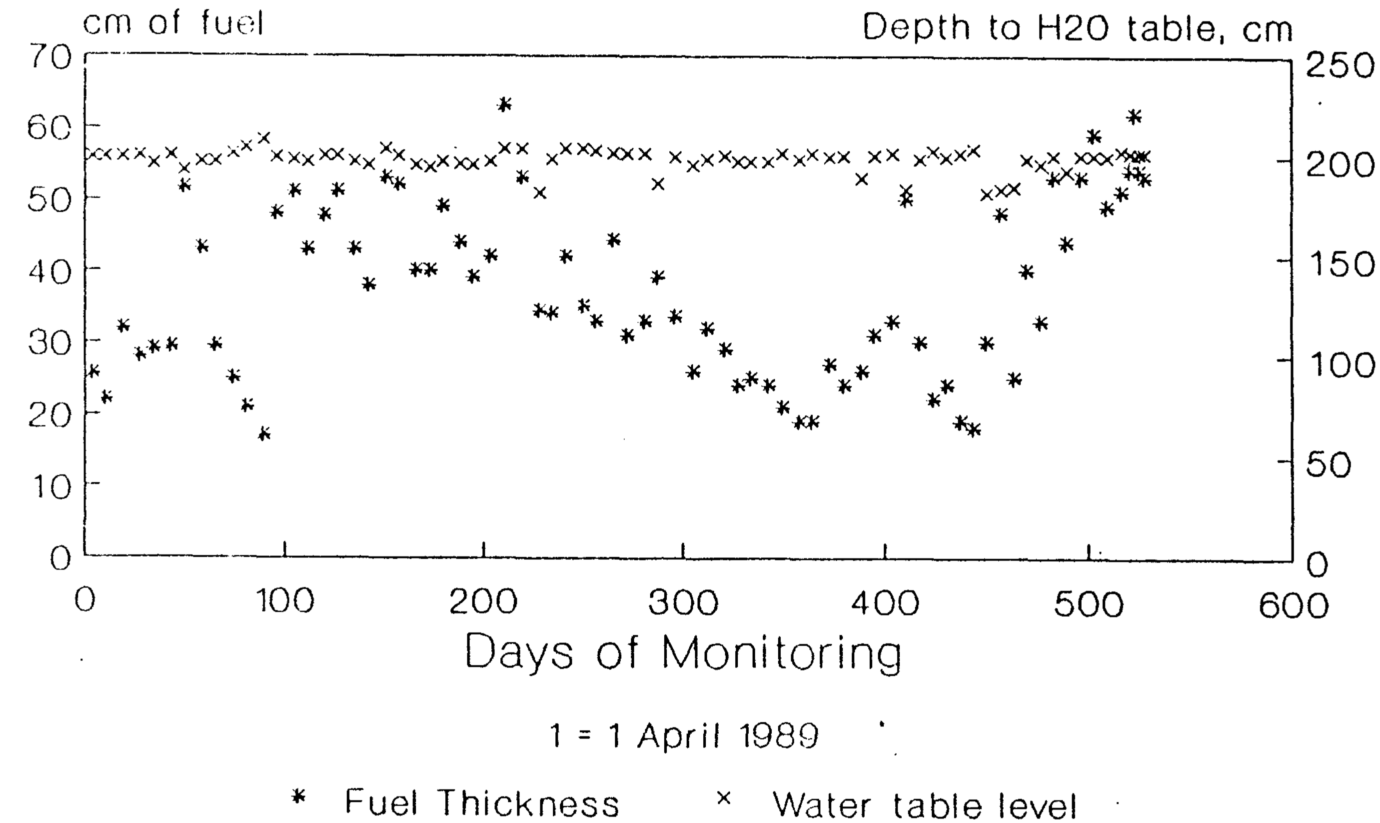
TABLE B-1. OBSERVED FUEL THICKNESS AND DEPTH TO H_2O READINGS, HOMESTEAD AFB FL, 1989.

1989	Well I-18 Fuel Thickness cm	Well I-18 Depth to Water cm
3 April	25.6	199
10 April	22.0	199
17 April	32.0	199
24 April	28.0	200
1 May	29.0	196
8 May	29.3	200
15 May	51.5	192
22 May	43.2	197
29 May	29.6	197
5 June	25.0	201
12 June	21.0	204
19 June	17.0	208
26 June	48.0	199
3 July	51.0	198
10 July	43.0	197
17 July	47.6	200
24 July	51.0	200
31 July	43.0	197
7 August	38.0	195
14 August	53.0	203
21 August	52.0	200
28 August	40.0	195
4 September	40.0	194
11 Sept	49.0	197
18 Sept	44.0	196
25 Sept	39.0	195
2 October	42.0	197
9 Oct	63.0	203
16 Oct	53.0	203
24 Oct	34.4	181
30 Oct	34.0	198
6 November	42.0	203
13 Nov	35.0	203
20 Nov	33.0	202
27 Nov	44.2	201
4 December	31.0	201
11 Dec	33.0	201
18 Dec	39.0	186
26 Dec	33.5	199

TABLE B-2. OBSERVED FUEL THICKNESS AND DEPTH TO H_2O READINGS, HOMESTEAD AFB FL, 1990.

Homestead AFB FL 1990	Well I-18 Fuel thickness cm	Well I-18 Depth to water cm
2 January	26.0	195
9 Jan	32.0	198
16 Jan	29.0	200
22 Jan	24.0	197
29 Jan	25.0	197
5 February	24.0	197
12 Feb	21.0	201
19 Feb	19.0	198
26 Feb	19.0	201
5 March	27.0	199
12 March	24.0	200
19 March	26.0	189
26 March	31.0	200
2 April	33.0	201
9 April	50.0	183
16 April	30.0	198
23 April	22.0	202
30 April	24.0	199
7 May	19.0	201
14 May	18.0	203
21 May	30.0	181
28 May	48.0	183
4 June	25.0	184
11 June	40.0	198
18 June	33.0	196
25 June	53.0	200
2 July	44.0	192
9 July	53.0	200
16 July	59.0	200
23 July	49.0	199
30 July	51.0	202
6 August	54.0	201
13 August	62.0	200
20 August	54.0	201
27 August	53.0	201
	Average 37	Average 198
	High 63.0	
	low 17.0	

Figure B-2. Homestead AFB FL Well I-18
JP-4 thickness & H20 table depths



From: 1988 AF
IRP Report

PROJECT NUMBER	BORING NUMBER
SEF26090.01	SB-2 SHEET 1 OF 1

SOIL BORING LOG

PROJECT Homestead Air Force Base LOCATION South Boring - Stripper

ELEVATION Unknown DRILLING CONTRACTOR [redacted]

DRILLING METHOD AND EQUIPMENT SPT Continuous - D40L22 (Mobile Drill); 2" Sampler

WATER LEVEL AND DATE 2.5' Below Grade START 4:40 FINISH 5:00 LOGGER R. Olson

DEPTH BELOW SURFACE (FT)	SAMPLE: INTERVAL	SAMPLE: TYPE AND NUMBER	SAMPLE: RECOVERY (FT)	STANDARD PENETRATION TEST RESULTS 6"-6"-6" (N)	SOIL DESCRIPTION: SOIL NAME, COLOR, MOISTURE CONTENT, RELATIVE DENSITY OR CONSISTENCY, SOIL STRUCTURE, MINERALOGY, USCS GROUP SYMBOL	SYMBOLIC LOG	COMMENTS: DEPTH OF CASING, DRILLING RATE, DRILLING FLUID LOSS, TESTS AND INSTRUMENTATION
				1	SURFACE ORGANICS		
2		2-1	50%	7, 14, 13 (21)	Sandy silt, grey, moist, very stiff, brittle, (ML)		
4		2-2	75%	5, 7, 11, 16 (18)	Fractured Lime Rock w/ Silt, white, saturated, medium dense.		
6		2-3	100%	17, 13, 26, 19 (39)	As above with sand and very little silt, dense. Fractured lime rock w/silt, white, saturated, highly weathered, medium dense.		
8		2-4	100%	10, 9, 11, 11 (19)			
		2-5	75%	9, 8, 13 (21)			
10				50/1"	Refusal. Could not auger through		End of boring @ 9.5' below ground surface.

FIGURE B-3
SOIL BORING LOG SB-2, HOMESTEAD

From: 1988 AF
IRP Report

PROJECT NUMBER	BORING NUMBER	SHEET
SEF26095.C1	SB-1	1 OF 1

SOIL BORING LOG

PROJECT Homestead Air Force Base LOCATION North Boring - Tank

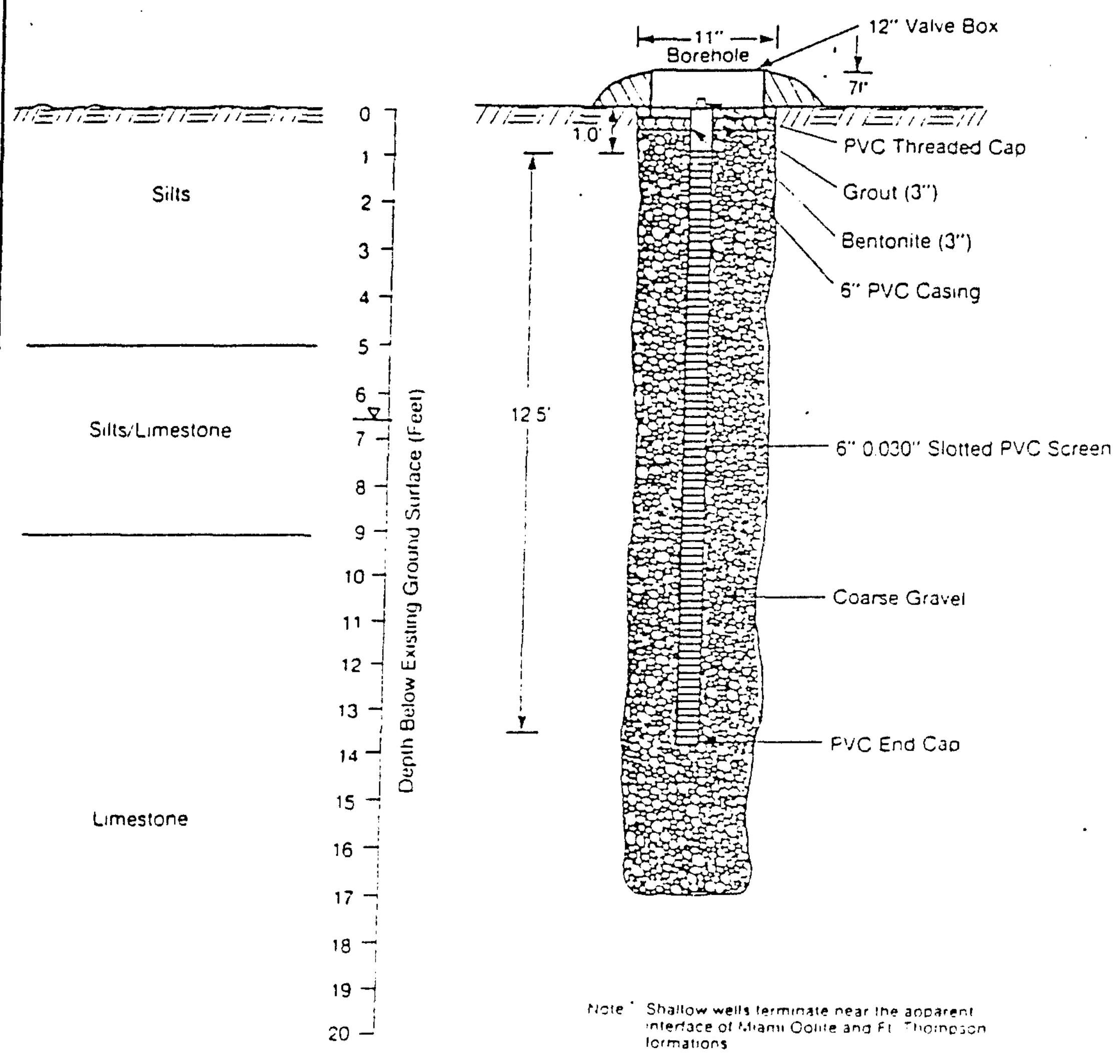
ELEVATION Unknown DRILLING CONTRACTOR [redacted]

DRILLING METHOD AND EQUIPMENT SPT Continuous D40L22 (Mobile Drill); 2' Sampler

WATER LEVEL AND DATE 1' Below Grade START 3:50 FINISH 4:30 LOGGER R. Olson

DEPTH BELOW SURFACE (FT)	SAMPLE: INTERVAL	SAMPLE: TYPE AND NUMBER	SAMPLE: RECOVERY (FT)	STANDARD PENETRATION TEST RESULTS 6"-6"-6" (N)	SOIL DESCRIPTION: SOIL NAME, COLOR, MOISTURE CONTENT, RELATIVE DENSITY OR CONSISTENCY, SOIL STRUCTURE, MINERALOGY, USCS GROUP SYMBOL	SYMBOLIC LOG	COMMENTS: DEPTH OF CASING, DRILLING RATE, DRILLING FLUID LOSS, TESTS AND INSTRUMENTATION
0–2		1-1	50%	2, 11, 20, 20 (31)	SURFACE ORGANICS Sandy silt, grey, moist, very stiff, (ML)		
2–4		1-2 1-3	50%	16, 29, 19, 14 (47)	FRACTURED LIME ROCK W/ SHELL No recovery		
4–6		1-4	100%	12, 13, 25, 28 (38)	FRACTURED/WEATHERED LIMEROCK Rock w/fine sand and silt, saturated, dense.		
6–8		1-5	100%	9, 8, 23, 12 (31)			
8–10		1-6	60%	8, 13, 3, 5 (16)			
10		1-7	25%	41, 50/2"	HIGHLY FRACTURED LIMESTONE Refusal/Could not auger through		End of boring @ 10' below ground surface.

FIGURE B-4
SOIL BORING LOG SB-1, HOMESTEAD



Note: Shallow wells terminate near the apparent interface of Miami Oolite and Ft. Thompson formations

Boring logs depict generalized subsurface conditions only at the specific locations and at the time of drilling. Generalized logs were based on field logs as estimated and recorded by on-site representatives during drilling

From: 1988 AF IRP REPORT

FIGURE B-5
CONSTRUCTION DIAGRAM MW3S
HOMESTEAD AFB SITE 9.

APPENDIX C

LANGLEY AFB VA

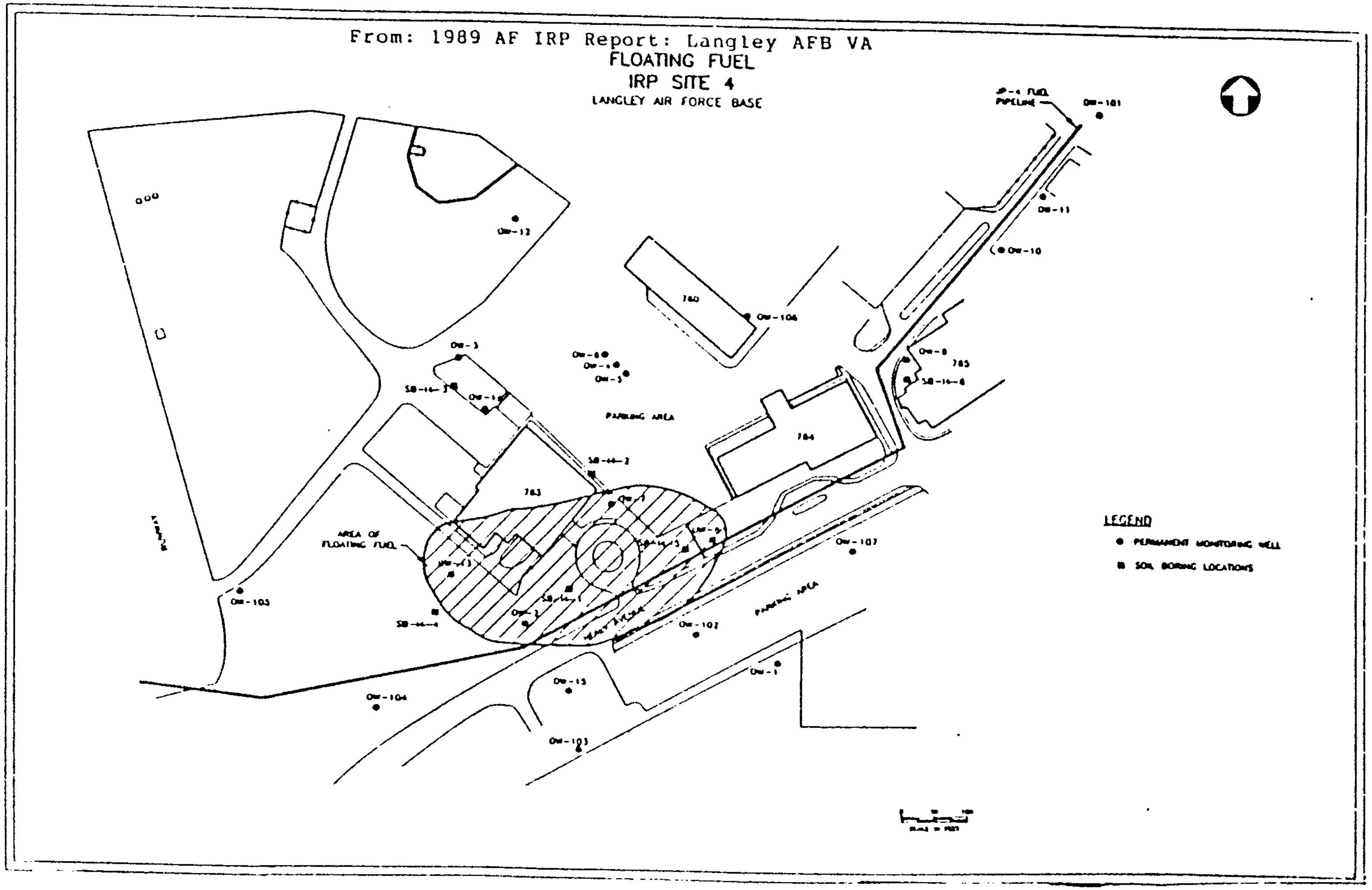


FIGURE C-1
AREA OF FLOATING FUEL
IRP SITE 4, LANGLEY AFB VA

TABLE C-1. OBSERVED FUEL THICKNESS READINGS, LANGLEY AFB

Langley AFB VA 1989	Well 2 Fuel Thickness cm	Well 7 Fuel Thickness cm	Well 11 Fuel Thickness cm
15 March	0.3	10.4	1.2
16 March	0.3	10.4	1.2
22 March	0.6	19.8	10.7
23 March	0.6	19.8	10.7
29 March	0.9	14.3	6.7
5 April	0.9	18.6	7.6
12 April	6.7	12.2	5.8
19 April	6.0	13.7	5.8
26 April	22.2	20.4	9.1
3 May	18.6	18.6	6.7
10 May	22.2	19.2	13.1
17 May	17.0	19.5	6.7
24 May	23.2	5.5	6.0
31 May	17.7	11.0	4.3
7 June	6.0	13.7	6.4
14 June	9.2	9.3	1.2
21 June	0.6	not measured	6.7
28 June	15.2	24.7	1.5
5 July	13.1	33.0	9.7
12 July	32.0	17.7	8.2
19 July	33.2	8.5	9.1
26 July	38.4	16.7	9.4
2 August	33.5	20.4	9.4
9 August	30.8	21.6	12.2
16 August	33.5	21.3	9.7
23 August	9.2	16.1	1.8
6 Sept	1.5	2.1	8.5
13 Sept	29.8	17.0	7.9
20 Sept	27.4	23.5	10.9
27 Sept	25.3	2.4	8.3
4 October	28.6	17.0	38.4
11 October	2.3	5.2	8.8
18 October	7.9	24.7	4.8
25 October	1.5	9.1	2.7
1 November	1.5	2.1	8.5
8 November	9.4	16.1	1.8
15 November	0.9	14.3	12.2
20 November	0.9	12.8	11.8
27 November	2.1	11.3	10.3
6 December	zero	15.8	10.0
13 December	2.4	7.6	1.5
20 December	zero	15.5	11.3
	average 13.3	average 15.1	average 8.1
	low 0.30	low 2.10	low 1.20
	high 38.4	high 33.0	high 38.4

TABLE C-1. OBSERVED FUEL THICKNESS READINGS, LANGLEY AFB VA, 1989 (CONTINUED).

1989	Fuel Thickness cm
15 March	0.3
16 March	0.3
22 March	0.3
23 March	0.3
29 March	6.0
5 April	0.3
12 April	0.3
19 April	1.2
26 April	3.3
3 May	1.8
10 May	3.6
17 May	4.6
24 May	5.5
31 May	10.0
7 June	2.1
14 June	0.3
21 June	0.9
28 June	0.9
5 July	21.3
12 July	7.6
19 July	7.3
26 July	14.0
2 August	7.6
9 August	8.8
16 August	6.4
23 August	0.6
6 Sept	1.5
13 Sept	10.6
20 Sept	8.5
27 Sept	3.3
4 October	14.3
11 October	5.5
18 October	1.2
25 October	10.4
1 November	1.5
8 November	0.6
15 November	0.1
20 November	zero
27 November	zero
6 December	17.7
13 December	4.3
20 December	17.4
	average
	5.3
	low
	0.3
	high
	17.7

TABLE C-2. OBSERVED DEPTH TO WATER READINGS, LANGLEY AFB VA, 1989.

Langley AFB VA 1989	Well 2 Depth to Water cm	Well 7 Depth to Water cm	Well 11 Depth to Water cm
15 March	64	110	112
16 March	64	110	112
22 March	70	120	132
23 March	70	120	132
29 March	73	112	132
5 April	94	135	139
12 April	82	120	131
19 April	87	123	134
26 April	122	147	147
3 May	119	145	131
10 May	122	146	147
17 May	120	150	139
24 May	131	139	140
31 May	122	144	138
7 June	83	123	135
14 June	122	111	112
21 June	71	not measured	132
28 June	125	116	111
5 July	130	143	142
12 July	158	163	144
19 July	158	152	144
26 July	165	161	145
2 August	165	168	148
9 August	168	174	156
16 August	165	168	149
23 August	107	145	122
6 Sept	97	144	134
13 Sept	158	161	143
20 Sept	158	171	152
27 Sept	151	143	134
4 October	156	161	175
11 October	97	141	136
18 October	78	116	112
25 October	99	110	116
1 November	99	144	135
8 November	107	145	121
15 November	90	139	143
20 November	96	143	144
27 November	100	139	144
6 December	178	156	148
13 December	113	135	97
20 December	175	155	146
	average 117	average 140	average 135

TABLE C-2. OBSERVED DEPTH TO WATER READINGS, LANGLEY AFB VA, 1989 (CONTINUED).

Langley AFB 1989	Well 13 Depth to Water cm
15 March	108
16 March	108
22 March	116
23 March	116
29 March	128
5 April	154
12 April	125
19 April	131
26 April	168
3 May	167
10 May	168
17 May	171
24 May	177
31 May	180
7 June	132
14 June	108
21 June	126
28 June	108
5 July	189
12 July	196
19 July	194
26 July	196
2 August	197
9 August	201
16 August	196
23 August	147
6 Sept	146
13 Sept	192
20 Sept	194
27 Sept	141
4 October	194
11 October	152
18 October	109
25 October	121
1 November	146
8 November	147
15 November	146
20 November	147
27 November	147
6 December	129
13 December	102
20 December	136
	average 156

Figure C-2. Langley AFB VA Well 2
JP-4 Thickness & H20 table depths

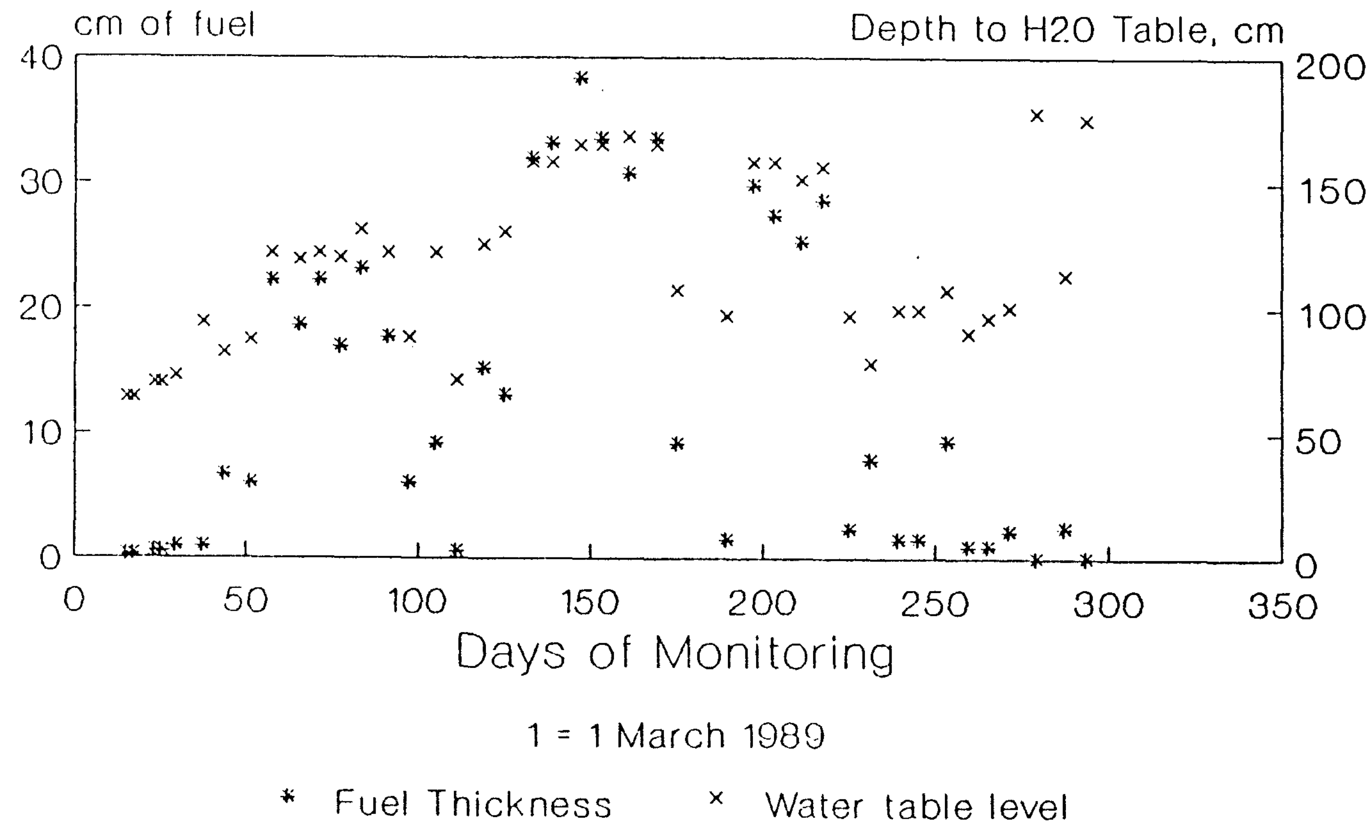


Figure C-3. Langley AFB VA Well 7 JP-4 Thickness & H20 table depths

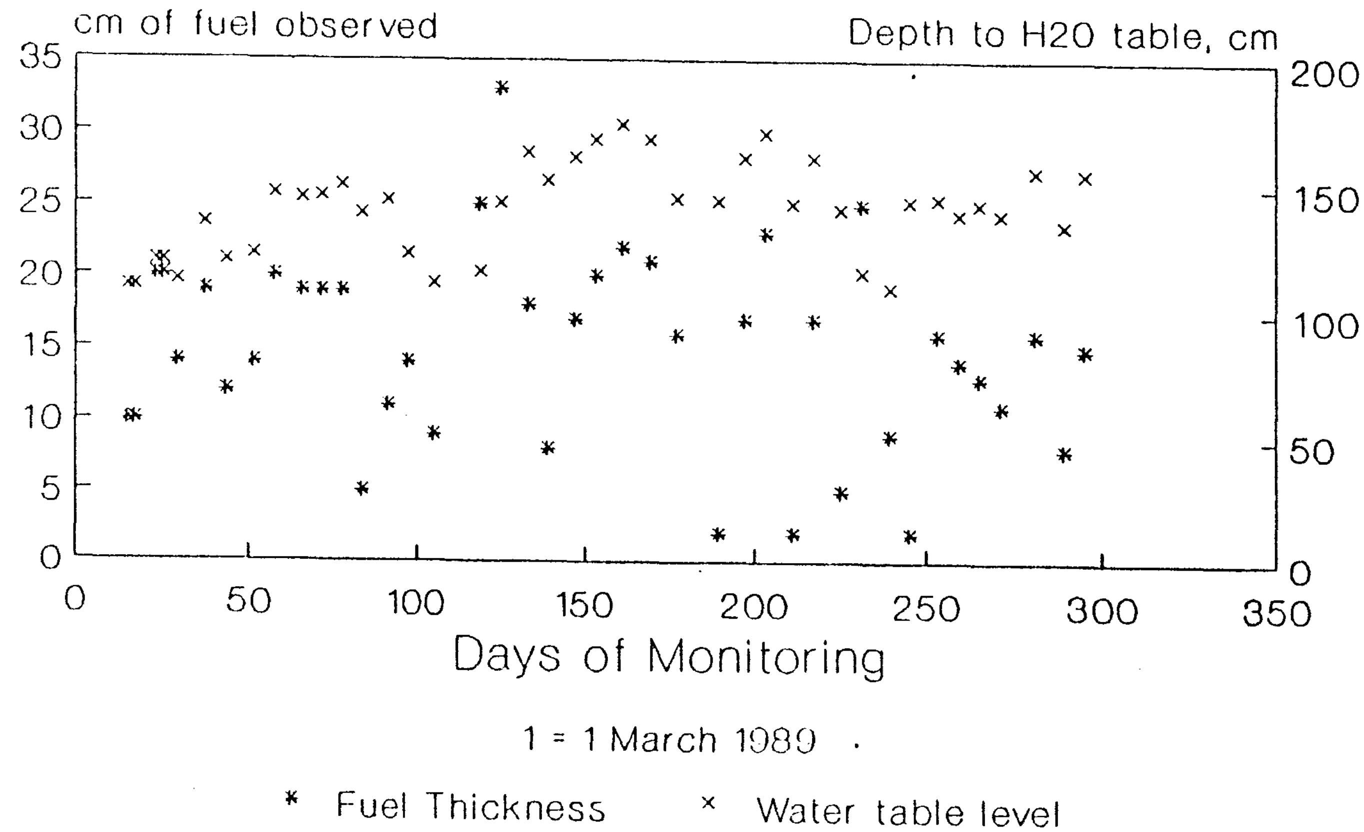


Figure C-4. Langley AFB VA Well 11
JP-4 Thickness & H20 table depths

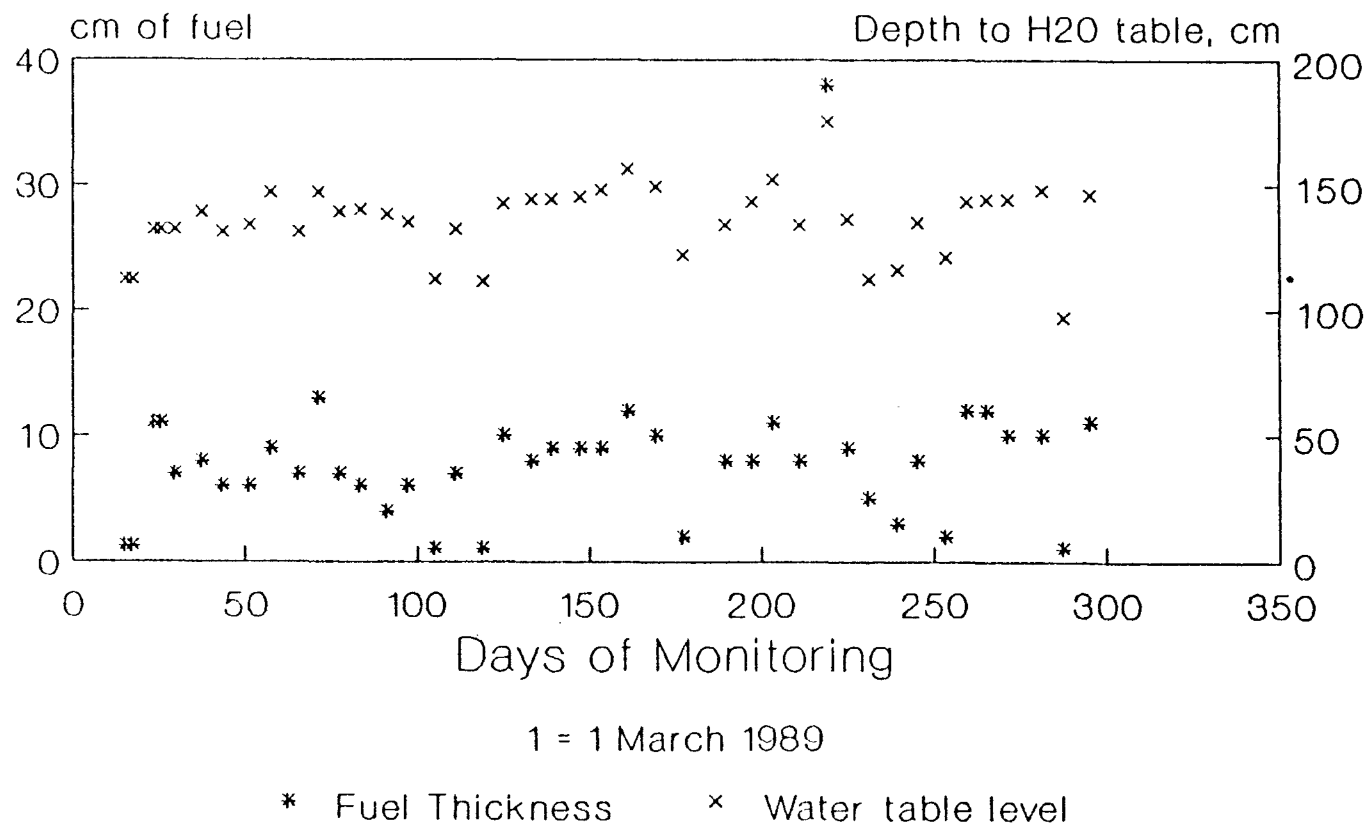
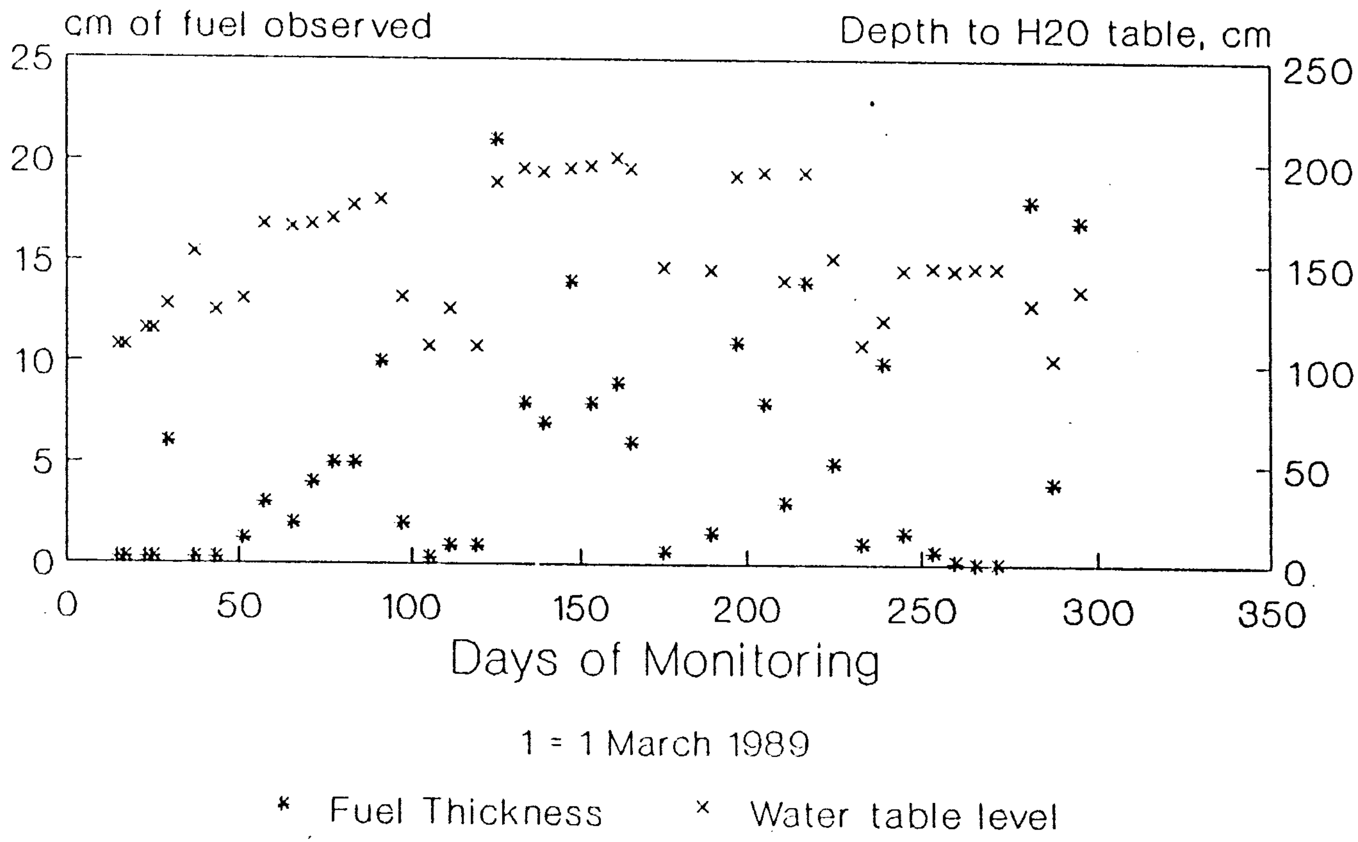


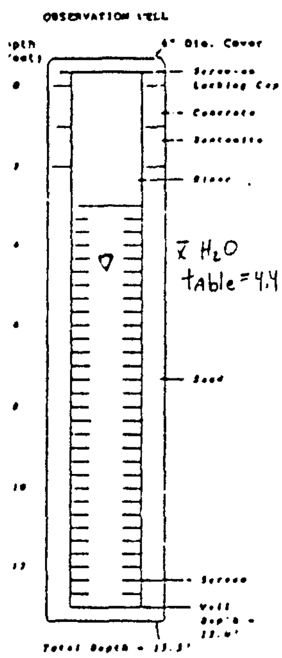
Figure C-5. Langley AFB VA Well 13
JP-4 Thickness & H20 table depths



From: 1989 AF IRP Report

BORING LOG
Boring No. OW11
Sheet 1 Of 2

Job No. 86014-4/5	Client Langley AFB	Project Langley AFB, IRP Site 4
Location Langley AFB, Hampton, VA		Elevation Ground 8.97'
Drilling Co [redacted]	Driller [redacted]	Inspector TLW
Rig Type CME-45-C	Bit Type 4" ID H.S.A.	Date Start & Finish 4-8-88 4-8-88
Sampler Type 2" ID Split Spoon	Hammer Drop 30"	T.D. 13.5' / Water Level



Boring/Well Construction	Sample No.	Rec	6"	Depth Ft.	Description of Soil	Remarks
	1 (0'-2')	20.7"	2-7 9-9	0'-0.3'	Clay, silty with gravel, roots, moist, no hydrocarbon odor, gray (N6)	
				0.3'-0.7'	Asphalt	
				0.7'-2.0'	Clay, silty, slightly moist, brown (5yr 3/4) 1.0' - large gravel present 1.8' - red brick fragments present (5R 4/6)	
	2 (2'-4')	7.5"	4-4 6-7	2.0'-5.5'	Clay, dense, dark gray (N4), slightly moist, slight hydrocarbon odor	
	3 (4'-6')	25.0"	4-4 5-6		4.0' - becomes reddish-brown (5yr 4/4) & gray (N6) mottle, slight hydrocarbon odor	
				5.5'-8.0'	Clay, silty gray (N6), moist, moderate hydrocarbon odor	
	4 (6'-8')	12.0"	2-3 2-2		6.5' - becomes less dense, very moist, some gravel present, some bluish-gray (5B 4/1) laminated areas	

Materials:

1. Casing - 2.0" OD Schedule 40 PVC, "Ten-Slot" (0.010")
2. Sand - VA Materials #2 Sand, Washed Silica
3. Bentonite - 0.25" Pellets

FIGURE C-6
BORING LOG OW-11, LANGLEY

BORING LOG
Boring No. OW11
Sheet 2 Of 2

Job No. 86014-4/5	Client Langley AFB	Project Langley AFB, IRP Site 4	
Location Langley AFB, Hampton, VA		Elevation Ground 8.97'	
Drilling Co. [redacted]	Driller [redacted]	Inspector TLW	
Rig Type CME-45-C	Bit Type 4" ID H.S.A.	Date Start & Finish 4-8-88 4-8-88	
Sampler Type 2" ID Split Spoon	Hammer Drop 30"	T.D.	Water Level

Boring/Well Construction	Sample No.	Sample Rec	Sample 6"	Depth Ft.	Description of Soil	Remarks
	5 (8'-10')	20.5"	1-2 1-3	8.0'-12.0'	Fine sands with shell fragments, moist, reddish-brown (5yr 4/4) 8.1' - changes to bluish-gray (5B 4/1), moist, no hydrocarbon odor 9.0' - becomes wet 9.5' - becomes moist	
	6 (10'-12')	25.0"	4-4 6-9		10.0'- becomes wet 10.5'- becomes moist	
					Boring terminated at 13.5'	

FIGURE C-6
BORING LOG OW-11 (CONTINUED)

From: 1989 AF IRP Report: Langley

BORING LOG
Boring No. OW2
Sheet 1 Of 2

Job No. 86014-4/5	Client Langley AFB	Project Langley AFB, IRP Site 4
Location Langley AFB, Hampton, VA		Elevation Ground 7.93'
Drilling Co [redacted]	Driller [redacted]	Inspector TLW
Rig Type CME-45-C	Bit Type 4" ID H.S.A.	Date Start & Finish 4-7-88 4-7-88
Sampler Type 2" ID Split Spoon	Hammer Drop 30"	T.D. 13.5' / Water Level

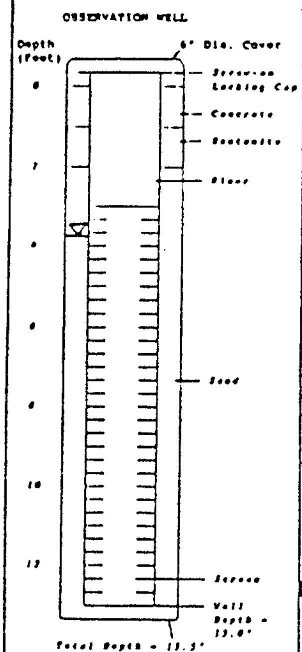
Boring/Well Construction	Sample No.	Sample Rec	Sample 6"	Depth Ft.	Description of Soil	Remarks
	1 (0'-2')	17.5"	3-7 7-7	0.0'-0.5'	Coarse sandy soil, some silt and gravel present, slightly moist	
				0.5'-6.0'	Clay, silty, with some fine sand, slightly moist, brown (5yr 3/4) .75' - occassional gravel present 2.5' - becomes gray (N4) 2.9' - dark gray (N4) and reddish-brown (5yr 4/4) mottle, slightly moist, Hydrocarbon odor 3.0' - some gravel present 4.0' - becomes gray (N6) 4.5' - becomes very moist 5.0' - dark gray (N4) and reddish-brown (5yr 4/4) mottle	$\bar{x}$ H_2O = 3.83'
	2 (2'-4')	16.5"	5-5 6-6			
	3 (4'-6')	23.0"	2-1 1-1			
Materials: 1. Casing - 2.0" OD Schedule 40 PVC, "Ten-Slot" (0.010") 2. Sand - VA Materials #2 Sand, Washed Silica 3. Bentonite - 0.25" Pellets	4 (6'-8')	17.0"	3-5 7-12	6.0'-14.0'	Fine to medium sands with shell fragments, very moist, reddish-brown (5yr 4/4), less hydrocarbon odor 7.0' - becomes bluish-gray, (5B 4/4) less shell fragments present, moist 8.3' - gravel present, moderate hydrocarbon odor 9.5' - more shell fragments present 10.0' - wet, no hydrocarbon odor 11.2' - becomes slightly moist	
	5 (8'-10')	22.5"	5-7 10-11			
	6 (10'-12')	25.0"	11-13 20-21			

FIGURE C-7
BORING LOG OW-2, LANGLEY

BORING LOG
Boring No. OW2
Sheet 2 Of 2

Job No. 86014-4/5	Client Langley AFB	Project Langley AFB, IRP Site 4	
Location Langley AFB, Hampton, VA		Elevation Ground 7.93'	
Drilling Co. [redacted]	Driller [redacted]	Inspector TLW	
Rig Type CME-45-C	Bit Type 4" ID H.S.A.	Date Start & Finish 4-7-88 4-7-88	
Sampler Type 2" ID Split Spoon	Hammer Drop 30"	T.D. 13.5'	Water Level

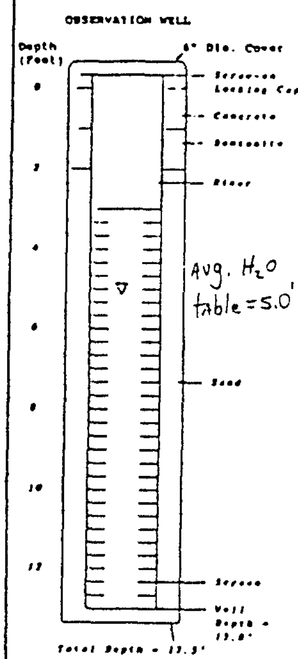
Boring/Well Construction	Sample No.	Sample Rec	Sample 6"	Depth Ft.	Description of Soil	Remarks
	7 (12'-14')	23.5"	5-11 16-24		12.0' - some gravel present, strong hydrocarbon odor 12.5' - laminated layer of reddish-brown (5yr 4/4) 13.0' - remains slightly moist, no hydrocarbon odor Boring terminated at 13.5'	

FIGURE C-7
BORING LOG OW-2 (CONTINUED)

From: 1989 AF IRP Report: Langley

BORING LOG
Boring No. OW13
Sheet 1 Of 1

Job No. 86014-4/5 Client Langley AFB	Project Langley AFB, IRP Site 4
Location Langley AFB, Hampton, VA	Elevation Ground 9.23'
Drilling Co [redacted] / Driller [redacted]	Inspector TLW
Rig Type CME-45-C / Bit Type 4" ID H.S.A.	Date Start & Finish 4-6-88 4-6-88
Sampler Type 2" ID Split Spoon / Hammer Drop 30"	T.D. 13.5' / Water Level

Boring/Well Construction	Sample No.	Rec	6"	Depth Ft.	Description of Soil	Remarks
	1 (0'-2')	10.5"	3-6 12-15	0'-7.0'	Clay, silty, dry, reddish-brown (5yr 4/4)	
					0.5'-0.8' - gravel present	
	2 (2'-4')	11.0"	7-5 7-8		2.0'-2.2' - becomes light brown (5yr 3/4)	
					2.2' - becomes gray (N6)	
	3 (4'-6')	20.0"	4-4 3-4		4.7' - becomes reddish-brown (5yr 4/4), & gray (N6), mottle	
					5.5' - becomes very moist with moderate hydrocarbon odor	
	4 (6'-8')	17.0"	3-4 2-3		6.0' - becomes very moist, strong hydrocarbon odor, dark gray (N4)	
				7.0'-12.0'	Fine to medium sands with shell fragments, dry, reddish-brown (5yr 4/4)	
	5 (8'-10')	16.0"	3-4 7-8		8.2' - becomes bluish-gray (5B 4/1), dry	
					8.9' - becomes moist	
	6 (10'-12')	15.2"	6-7 12-13		10.0' - becomes wet	
					11.0' - becomes slightly moist	
					Boring terminated at 13.5'	

Materials:

1. Casing - 2.0" OD Schedule 40 PVC, "Ten-Slot" (0.010")
2. Sand - VA Materials #2 Sand, Washed Silica
3. Bentonite - 0.25" Pellets

FIGURE C-8
BORING LOG OW-13, LANGLEY

From: 1989 AF IRP Report: Langley

BORING LOG
Boring No. OW7
Sheet 1 Of 2

Job No. 86014-4/5	Client Langley AFB	Project Langley AFB, IRP Site 4
Location Langley AFB, Hampton, VA		Elevation Ground 8.78'
Drilling Co. [redacted]	Driller [redacted]	Inspector TLW
Rig Type CME-45-C	Bit Type 4" ID H.S.A.	Date Start & Finish 4-10-88 4-10-88
Sampler Type 2" ID Split Spoon	Hammer Drop 30"	T.D. 13.5' / Water Level

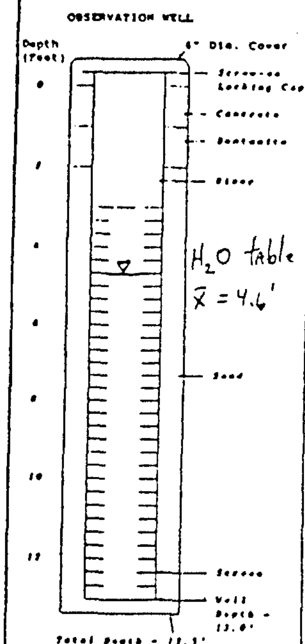
Boring/Well Construction	Sample No.	Rec	6"	Depth Ft.	Description of Soil	Remarks
	1 (0'-2')	17.5"	2-7 8-7	0'-1.4'	Top soil, silty, with some gravel, slightly moist	
				1.4'-8.7'	Clay, silty, slightly moist, reddish-brown (5yr 4/4) mottle	
	2 (2'-4')	13.0"	4-4 7-8		2.0' - some fine gravel present 2.5' - slightly moist, moderate hydrocarbon odor	
	3 (4'-6')	25.0"	3-3 3-3		5.5' - becomes darker, moist, strong hydrocarbon odor	
	4 (6'-8')	17.5"	3-2 3-2		7.4' - becomes brown (5yr 4/4), moist, moderate hydrocarbon odor	
	5 (8'-10')	25.0"	3-4 7-8		8.0' - becomes reddish-brown (5yr 4/4) & gray (N6) mottle, some gravel present, slight hydrocarbon odor	
Materials: 1. Casing - 2.0" OD Schedule 40 PVC, "Ten-Slot" (0.010") 2. Sand - VA Materials #2 Sand, Washed Silica 3. Bentonite - 0.25" Pellets				8.7'-12.0'	Fine sands and silt, slightly moist, reddish-brown (5yr 4/4) 8.8' - grades to medium sands with abundant shell fragments, bluish-gray (5B 4/1) 9.1' - grades to fine to medium sands, moist	

FIGURE C-9
BORING LOG OW-7, LANGLEY

BORING LOG
Boring No. OW7
Sheet 2 Of 2

Job No. 86014-4/5 Client Langley AFB		Project Langley AFB, IRP Site 4
Location Langley AFB, Hampton, VA		Elevation Gound 8.78'
Drilling Co. [redacted]	Driller [redacted]	Inspector TLW
Rig Type CME-45-C	Bit Type 4" ID H.S.A.	Date Start & Finish 4-10-88 4-10-88
Sampler Type 2" ID Split Spoon	Hammer Drop 30"	T.D. / Water Level

Boring/Well Construction	Sample No.	Sample Rec	Sample 6"	Depth Ft.	Description of Soil	Remarks
	6 (10'-12')	25.5"	12-20 30-34		10.0' - no hydrocarbon odor 11.3' - becomes darker gray (N4)	
					Boring terminated at 13.5'	

FIGURE C-9
BORING LOG OW-7 (CONTINUED)

From: 1989 AF IRP Report

PARTICLE SIZE DISTRIBUTION & PHYSICAL PROPERTIES

CLIENT Corps of Engineers

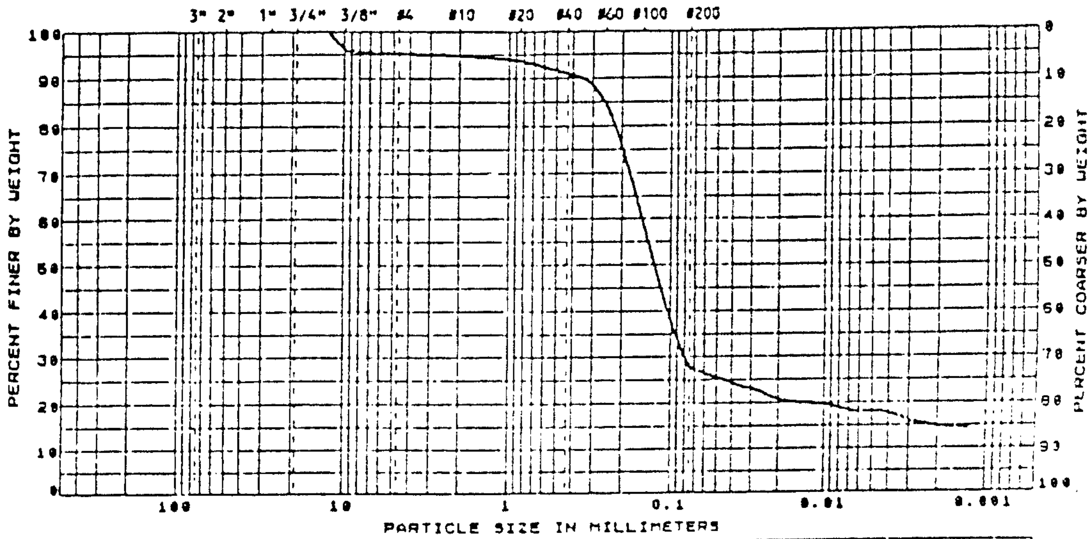
JOB NO. 11-0546 Task I01 DATE May 18, 1988

LAB NO. 9920 PAGE 3

PROJECT Langley A.F.B., IRP Site 4 Wells

SAMPLE ID OW-103 8.0'

U.S. STANDARD SIEVE SIZES



COBBLES	GRAVEL		SAND			SILT & CLAY
	COARSE	MEDIUM	CO.	MEDIUM	FINE	

U.S. STANDARD SIEVE SIZE		PERCENT PASSING		HYDROMETER
SIEVE NO.	SIEVE SIZE (MILLIMETERS)			PARTICLE DIAMETER (MILLIMETERS)
3"	75			0.050
2"	50		21.0	0.020
1-1/2"	37.5		18.0	0.005
1"	25		15.3	0.002
3/4"	19			0.001
1/2"	12.5	100.0		
3/8"	9.5	96.9		
#4	4.75	95.4		
#10	2.00	94.0		
#20	0.850	93.7		
#40	0.425	91.0		
#60	0.250	84.3	71	
#100	0.150	59.6		
#200	0.075	27.8		

POROSITY (%)

EFFECTIVE SIZE (mm)

COEFFICIENT OF UNIFORMITY

COEFFICIENT OF CURVATURE

LIQUID LIMIT 35

PLASTIC LIMIT 26

PLASTICITY INDEX 9

CLASSIFICATION SILTY SAND (SM)

WATER CONTENT (%) 28.2

DRY DENSITY (PCF)

SPECIFIC GRAVITY

HYDRAULIC CONDUCTIVITY (cm/sec - 20C)

TEST PROCEDURES: ASTM D422, D2216, D4319

FIGURE C-10
PARTICLE SIZE DISTRIBUTION
LANGLEY AFB IRP SITE 4 WELLS

APPENDIX D

WILLIAMS AFB AZ

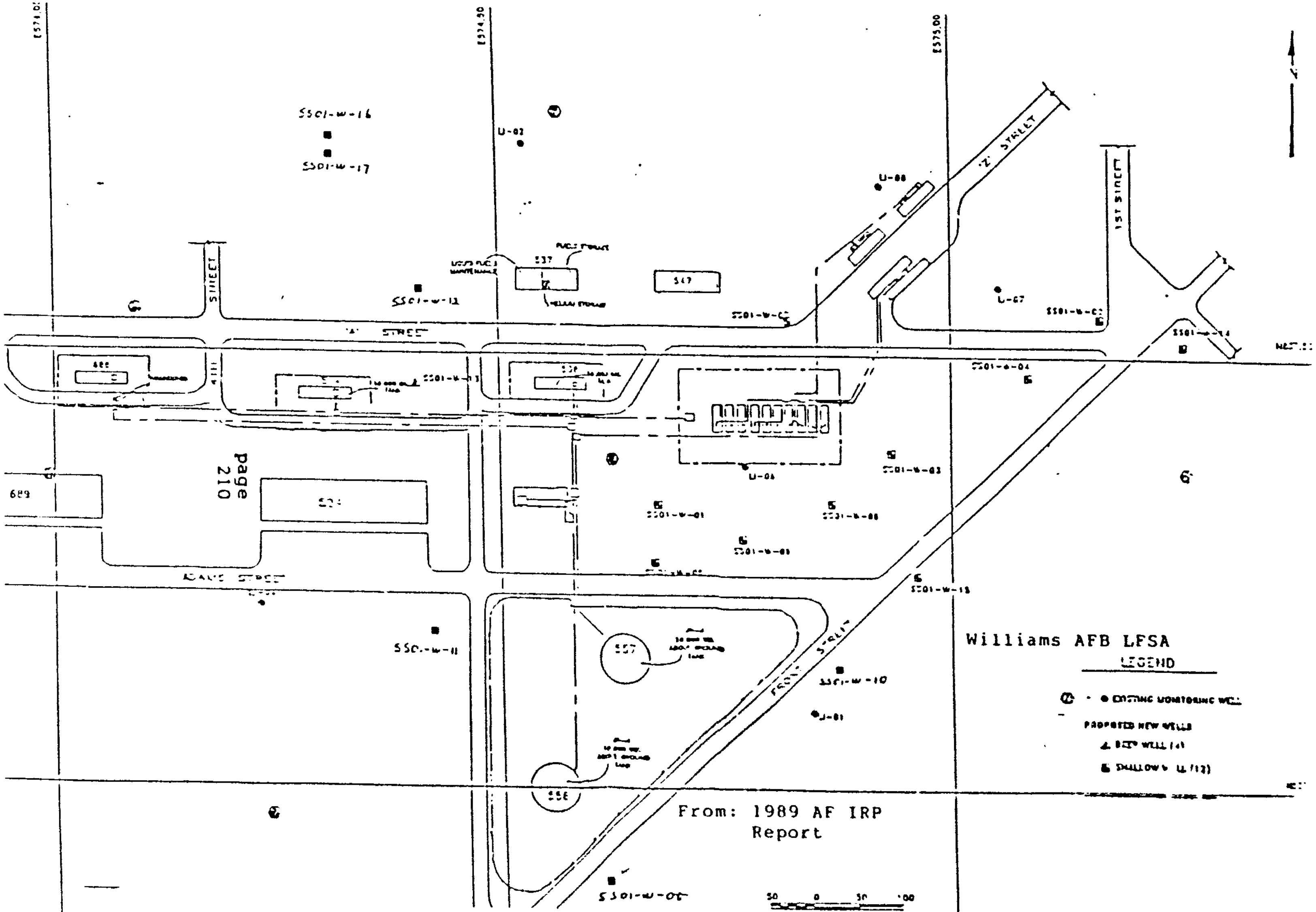


FIGURE D-1
LIQUID FUELS STORAGE AREA
WILLIAMS AFB AZ

TABLE D-1. OBSERVED FUEL THICKNESS READINGS, WILLIAMS AFB AZ, 1989.

Williams AFB 1989	Well LI-06 Fuel Thickness cm	Well W-01 Fuel Thickness cm	Well W-05 Fuel Thickness cm	Well W-09 Fuel Thickness cm	Well W-13 Fuel Thickness cm
31 January	283	not monitored	not monitored	not monitored	not monitored
16 February	255	nm	nm	nm	nm
23 Feb	320	nm	nm	nm	nm
3 March	308	nm	nm	nm	nm
7 March	293	nm	nm	nm	nm
7 April	271	nm	nm	nm	nm
14 April	271	nm	nm	nm	nm
21 April	271	nm	nm	nm	nm
5 May	268	nm	nm	nm	nm
10 May	271	nm	nm	nm	nm
27 May	256	nm	nm	nm	nm
2 June	250	nm	nm	nm	nm
16 June	250	nm	nm	nm	nm
23 June	245	nm	nm	nm	nm
2 July	241	nm	nm	nm	nm
13 July	233	nm	nm	nm	nm
28 July	221	nm	nm	nm	nm
7 August	215	nm	nm	nm	nm
26 August	213	294	nm	nm	nm
12 September	209	448	nm	nm	nm
2 October	218	323	nm	nm	nm
13 October	224	301	nm	nm	nm
19 October	not monitored	nm	30	nm	nm
20 November	254	363	297	212	232
20 December	179	317	223	232	149

TABLE D-2. OBSERVED FUEL THICKNESS READINGS, WILLIAMS AFB AZ, 1990.

Williams AFB	Well LI-06 Fuel Thickness	Well W-01 Fuel Thickness	Well W-05 Fuel Thickness	Well W-09 Fuel Thickness	Well W-13 Fuel Thickness
1990	cm	cm	cm	cm	cm
16 January	294	276	390	228	99
27 March	nm	279	426	32	34
30 April	306	304	415	245	187
23 May	304	327	391	261	208
18 July	293	443	242	338	259
27 August	274	427	131	246	82
	Average	Average	Average	Average	Average
	258	342	314	224	156
	low	low	low	low	low
	179	294	30	32	34
	high	high	high	high	high
	360	448	426	338	259

TABLE D-3. OBSERVED DEPTH TO WATER READINGS, WILLIAMS AFB AZ, 1989-90.

Williams AFB AZ	Well LI-06 Depth to water cm	Well W-01 Depth to water cm	Well W-05 Depth to water cm	Well W-09 Depth to Water cm	Well W-13 Depth to water cm
1989					
31 January	6780	not monitored	not monitored	not monitored	not monitored
16 Febraury	7018	nm	nm	nm	nm
23 Feb	7082	nm	nm	nm	nm
3 March	7051	nm	nm	nm	nm
7 March	7049	nm	nm	nm	nm
7 April	7053	nm	nm	nm	nm
14 April	7041	nm	nm	nm	nm
21 April	7056	nm	nm	nm	nm
5 May	7059	nm	nm	nm	nm
10 May	7062	nm	nm	nm	nm
27 May	7056	nm	nm	nm	nm
2 June	7059	nm	nm	nm	nm
16 June	7059	nm	nm	nm	nm
23 June	7059	nm	nm	nm	nm
2 July	7068	nm	nm	nm	nm
13 July	7064	nm	nm	nm	nm
28 July	7062	nm	nm	nm	nm
7 August	7062	nm	nm	nm	nm
26 August	7063	7148	nm	nm	nm
12 September	7063	7228	nm	nm	nm
2 October	7060	7125	nm	nm	nm
13 October	7061	7102	nm	nm	nm
19 October	not monitored	nm	6949	nm	nm
20 November	7056	7121	7121	7077	6959
20 December	6960	7070	7013	7072	6879
1990					
16 January	7045	7014	7137	7049	6815
27 March	nm	7009	7187	6817	6681
30 April	7047	7030	7165	7056	6883
23 May	7051	7058	7155	7076	6906
18 July	7075	7176	7045	7163	6976
27 August	7072	7173	6994	7102	6854
	Average 7045	Average 7105	Average 7085	Average 7052	Average 6869

Figure D-2. Williams AFB AZ Well LI-06
JP-4 Thickness & H20 table depths

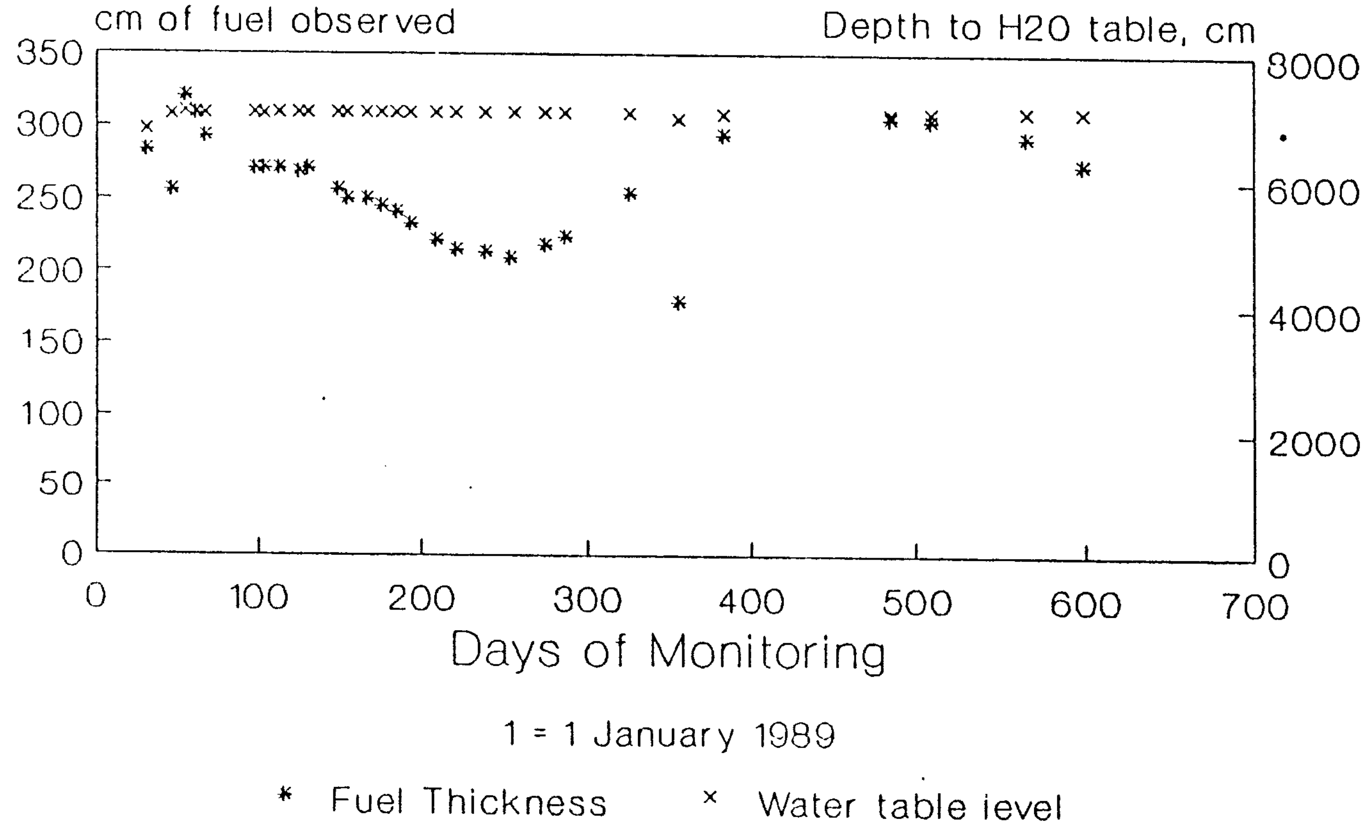


Figure D-3. Williams AFB AZ Well W-01
JP-4 Thickness & H20 table depths

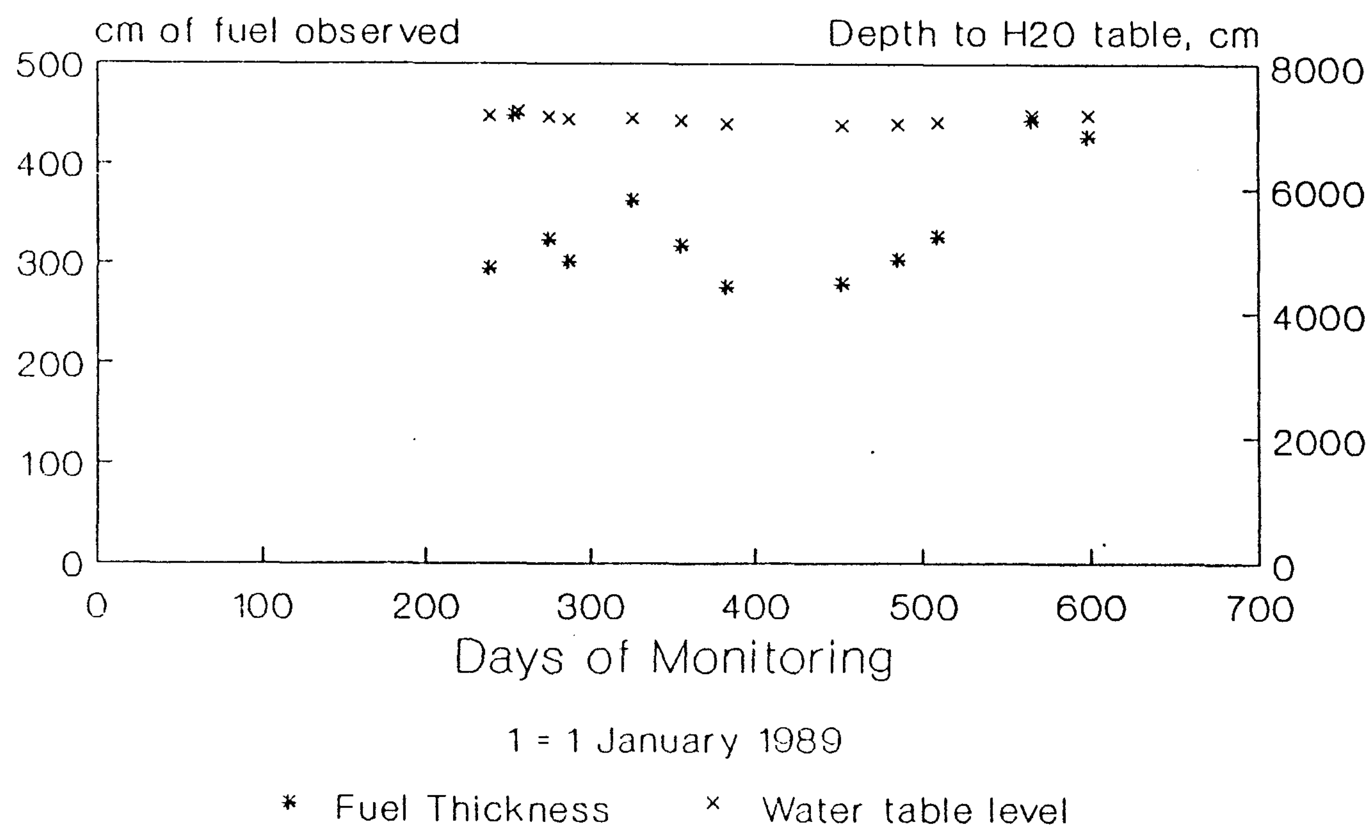


Figure D-4. Williams AFB AZ Well W-05
JP-4 Thickness & H20 table depths

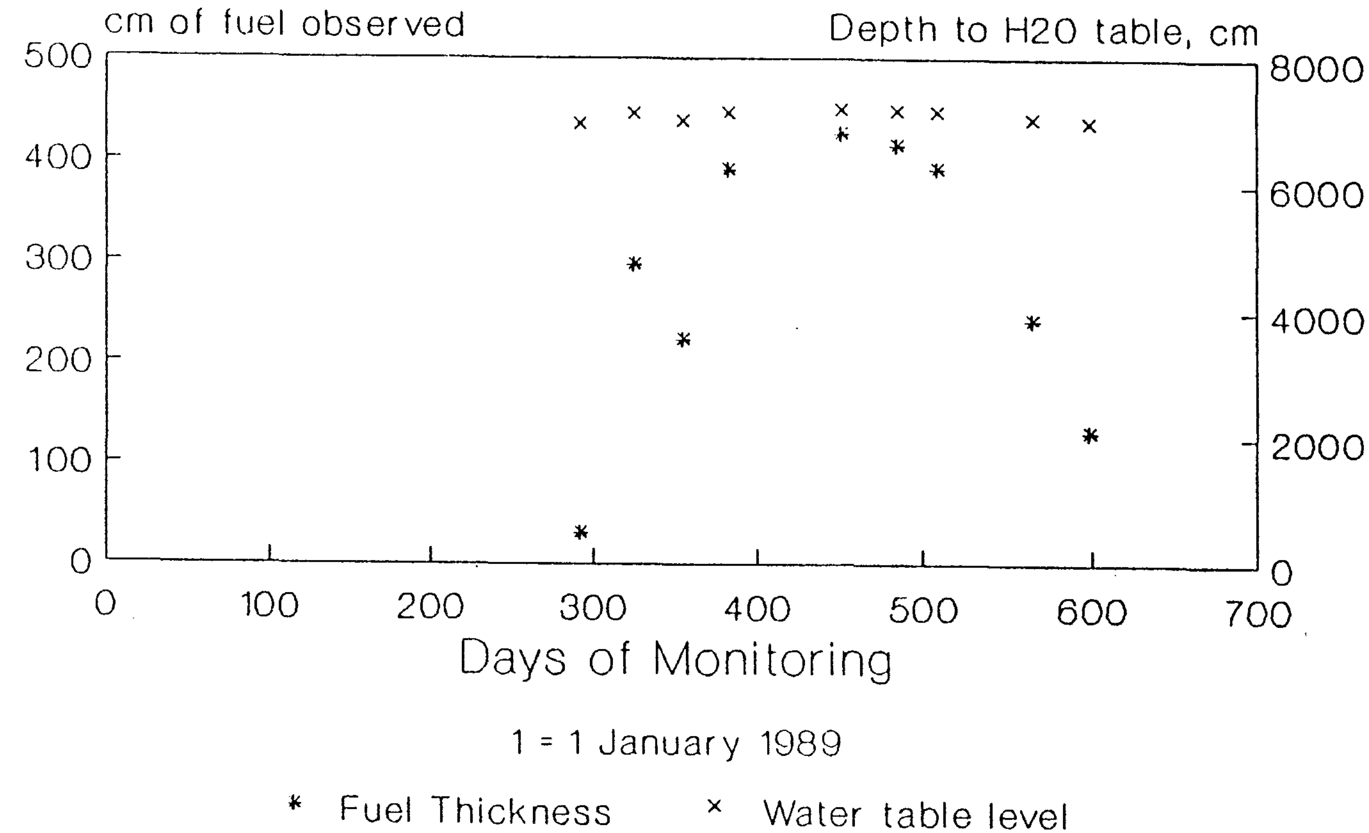


Figure D-5. Williams AFB AZ Well W-09
JP-4 Thickness & H20 table depths

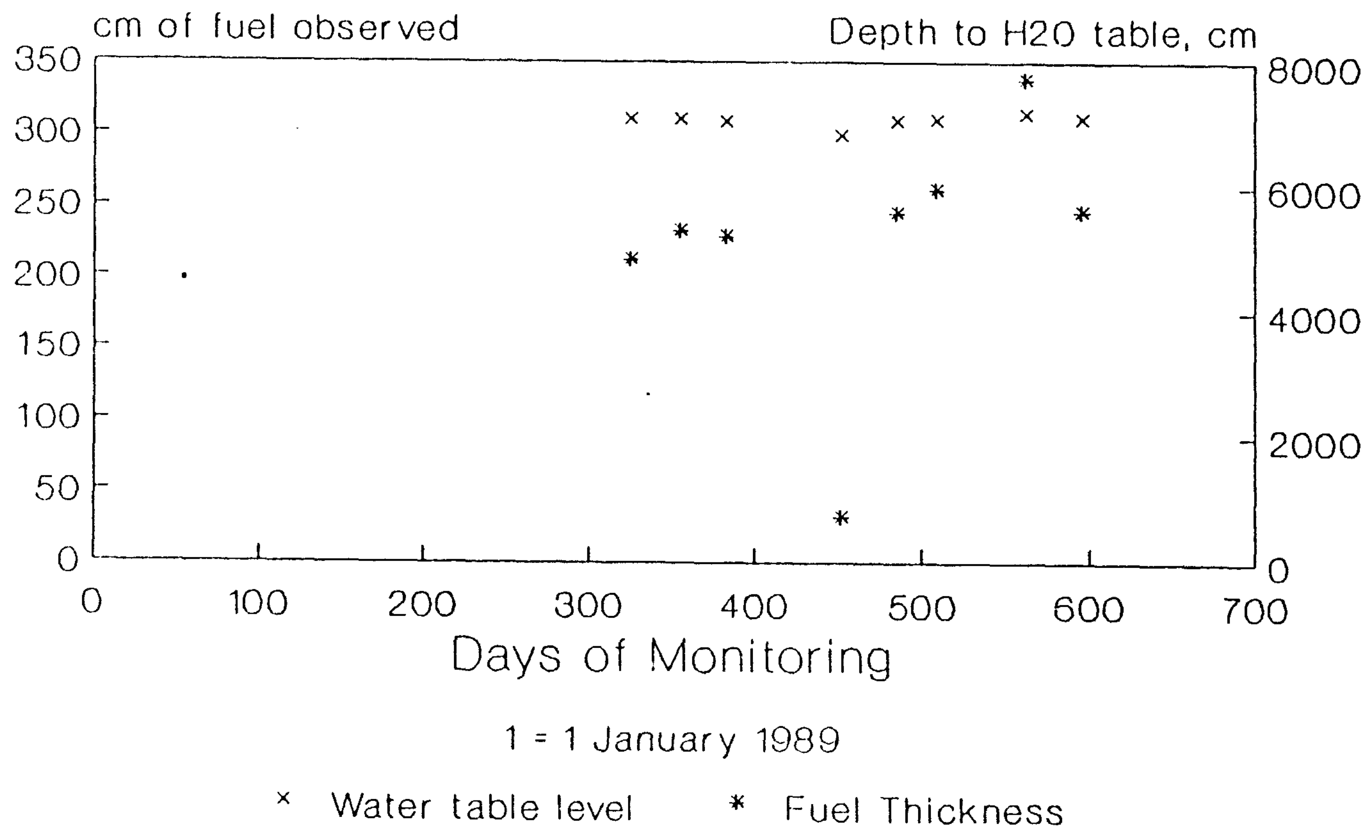
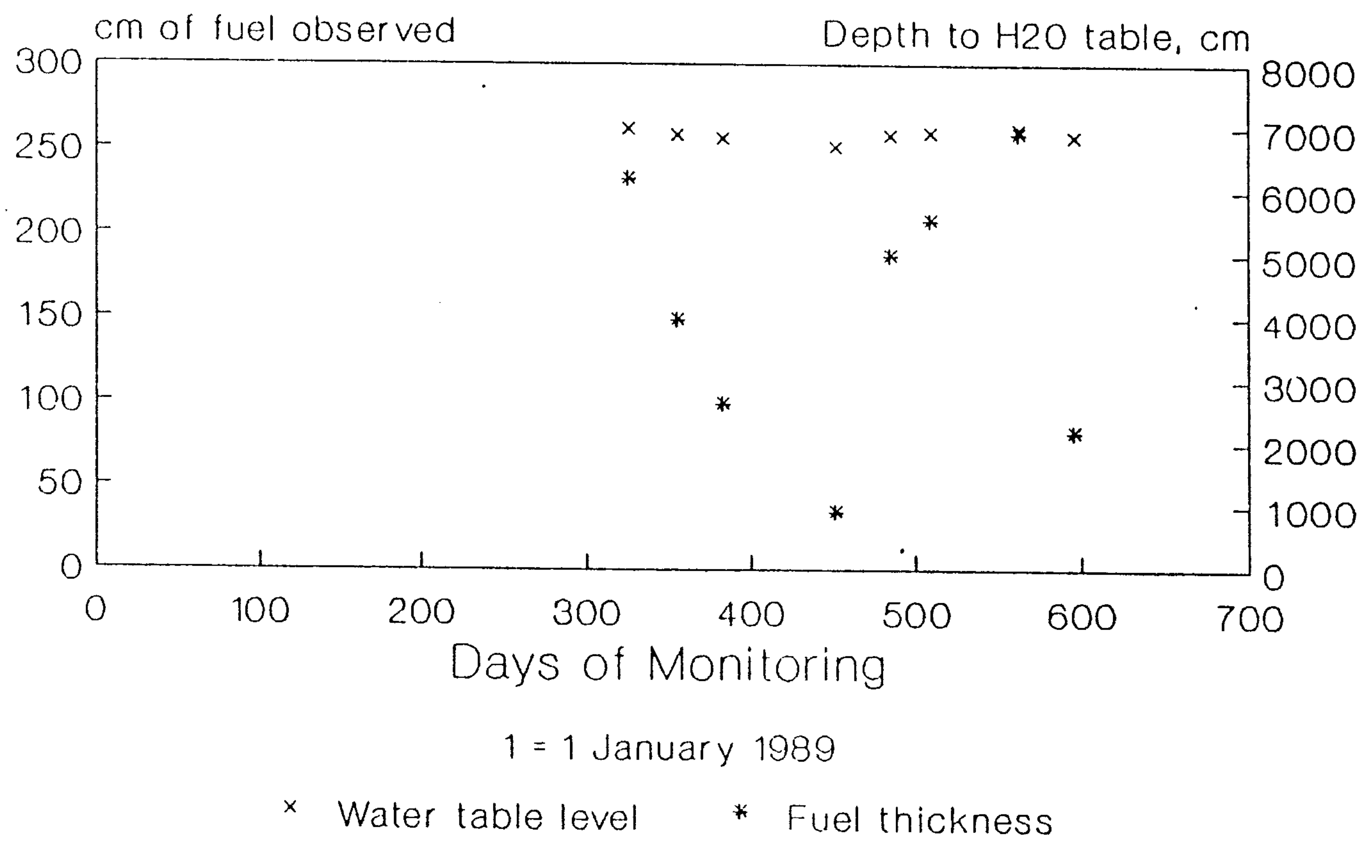


Figure D-6. Williams AFB AZ Well W-13
JP-4 Thickness & H20 table depths



VISUAL CLASSIFICATION OF SOILS

From: 1989 AF IRP Report, Williams AFB AZ

PROJECT No: 409659	PROJECT NAME: WILLIAMS AIR FORCE BASE, ARIZONA	
BORING NUMBER: SS01-W01	COORDINATES: NA	DATE: 7-25-89 TOC
ELEVATION: NA	GWL DEPTH DATE/TIME	START: 7-10-89
ENG./GEOL.: [redacted]		COMPLETE:
DRILL METHOD: 18" AUGER TO 18', 7 7/8" MUD ROTARY TO TOTAL DEPTH		PAGE 6 OF 9

DEPTH (FT)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 IN)	RECOVERY (%)	MATERIAL DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	HNu (ppm)	REMARKS
150								
155			120"	COBBLES				-Driller suggest this 10' interval (152-162ft) has alot of cobbles
					?			
160			36"	Silty CLAY, 10% SILT, 90% CLAY, plastic, coarse, brown (7.5YR5/4), damp	cl	3.2		-Driller suggest that 160-152ft. is soft and might be clay
			120"	Clayey SILT, 30% CLAY, 70% SILT, dense, brown, damp	ml	2.5		
				Clayey, silty SAND, cemented, some pebbles	sm			
165				fine SAND at 166ft, coarsens downward, silt decreases				
				- yellowish sediment at 169ft.				
170			72"		?			
			120"	Clayey SILT, 30% CLAY, COBBLES at 172ft, loose, brown, damp	ml	5		
				-cemented at 172.5ft.		>4.5		
				Silty SAND, 30% CLAY, 70% coarse SAND, loose, moist	sm	.5		
175								
180			24"					

NOTES: WELL SPECS

The pages 1-5 of this well log were not included in this report as they are not in the zone of influence. ERC

FIGURE D-7
WELL LOG, BORING SS01-W01
WILLIAMS AFB

VISUAL CLASSIFICATION OF SOILS

PROJECT No.: 409659	PROJECT NAME: WILLIAMS AIR FORCE BASE, ARIZONA	
BORING NUMBER: SS01-W01	COORDINATES: NA	DATE: 7-25-89 TOC
ELEVATION: NA	GWL DEPTH DATE/TIME:	START: 7-10-89
ENG./GEOL.: [redacted]		COMPLETE:
DRILL METHOD: 18" AUGER TO 18', 7 7/8" MUD ROTARY TO TOTAL DEPTH		PAGE 7 OF 9

DEPTH (FT)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 IN.)	RECOVERY (%)	MATERIAL DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	HNu (ppm)	REMARKS
180								
			120"	Clayey, silty SAND, 20% CLAY, 30% SILT, 50% fine SAND, density varies with % $CaCO_3$, color varies, damp	sm	>4.5 1.5 >4.5	85 85	
185								
190								
			30" 120"	Clayey, silty SAND, 10% CLAY, 30% SILT, 60% SAND, density varies (mostly loose), color varies (mostly brown), moist	sm	10	85	-Lower organic vapor readings in the clays
				Silty CLAY, 30% SILT, non plastic, pink (7.5YR7/4), damp	cl sp	>4.5		
195								
200								
			18"	Clayey, silty SAND, 10% CLAY, % SILT and SAND varies, color varies, damp	sm	10		-Core barrel pack off, very slow advancing -Calcite tubes (same as above)
			100"	-40% SILT, 50% fine SAND		>4.5	85	
205				-20% SILT, 70% medium SAND		10	5	
				-40% SILT, 50% fine SAND		>4.5	25	
				-30% SILT, 60% fine SAND		3.75	30	
210								

NOTES: WELL SPECS

FIGURE D-7
WELL LOG, BORING SS01-W01
WILLIAMS AFB (CONTINUED)

VISUAL CLASSIFICATION OF SOILS

PROJECT No: 409659	PROJECT NAME: WILLIAMS AIR FORCE BASE, ARIZONA	
BORING NUMBER: SS01-W01	COORDINATES: NA	DATE: 7-25-89 TOC
ELEVATION: NA	GWL:DEPTH DATE/TIME:	START: 7-10-89
ENG./GEOL.: [redacted]		COMPLETE:
DRILL METHOD: 18" AUGER TO 18', 7 7/8" MUD ROTARY TO TOTAL DEPTH		PAGE 8 OF 9

DEPTH (FT)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 IN)	RECOVERY (%)	MATERIAL DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	HNu (ppm)	REMARKS
210				Clayey, silty, SAND, 10% CLAY, 20% SILT, 70% fine SAND, loose, yellowish-red (5YR5/6), moist	sm	1.5	25	
			120"	GRAVEL, subrounded	?			
215					?			
220			12"	COBBLES				- Cobbles may be from interval above
			120"	Clayey SILT, 30% CLAY, loose, brown (7.5YR4/4)	ml	2.5	5	
				Clayey, silty SAND, 10% CLAY, 40% SILT, 50% pure SAND, brown, moist	sm	1.0		- Coarsening downward
225				- 30% SILT, 60% medium SAND			30	
				20% SILT, 70% coarse SAND				
				- PEBBLES at 228.0ft.			60	
				Silty CLAY, 30% SILT, nonplastic, compact, brown with red streaks, damp	cl	1.5		
230					?			
			84"	Clayey, sandy SILT, 20% CLAY, 20% SAND, 60% SILT, density varies, brown (7.5YR5/4)	ml		5	
			120"	Clayey, silty, SAND, 20% CLAY, 30% SILT, 50% fine SAND, density varies, mostly dense	sm	7 4.5		- Cement ($CACO_3$) 235.0ft. to 238.0ft
235							15	
240			49"					

NOTES: WELL SPECS

FIGURE D-7
WELL LOG, BORING SS01-W01
WILLIAMS AFB (CONTINUED)

VISUAL CLASSIFICATION OF SOILS

PROJECT No.: 409659	PROJECT NAME: WILLIAMS AIR FORCE BASE, ARIZONA	
BORING NUMBER: SS01-W01	COORDINATES: NA	DATE: 7-25-89 TOC
ELEVATION: NA	GWL:DEPTH DATE/TIME:	START: 7-10-89
ENG./GEOL.: [redacted]		COMPLETE:
DRILL METHOD: 18" AUGER TO 18', 7 7/8" MUD ROTARY TO TOTAL DEPTH		PAGE 9 OF 9

DEPTH (FT)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER (6 IN)	RECOVERY (%)	MATERIAL DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	PPM (ppm)	REMARKS
240			120"	Clayey, silty SAND, 10% CLAY, 30% SILT, 60% fine SAND, density varies, color varies with % $CaCO_3$ cementation, damp	sm		>4.5 18	T
245				Clayey, sandy SILT, 20% CLAY, 20% SAND, 60% SILT, density and color varies brown to light brown	ml		>4.5	
				Clayey, silty SAND, 10% CLAY, 30% SILT, 60% SAND (fine)	sm		18	
				Clayey, sandy, SILT	ml		>4.5	
250			96"	Clayey, silty SAND	sm		18	
				A				
				TOTAL DEPTH at 252.0ft.				
				R				
255			D					
260								
265								
270								

NOTES: WELL SPECS

FIGURE D-7
WELL LOG, BORING SS01-W01
WILLIAMS AFB (CONTINUED)

DRILLING RECORD

From 1988 US Air Force IRP Report

WELL NO. LI-06

Project Name Williams IRP No. 10416M Logged By [redacted]

Site LFSA Checked By [redacted]

Drilling Method Mud Rotary Date 3/6/87

Geologic Description	Graphic Log	Depth (ft.)	Well Design	Remarks
		10	grout / grout	
		20		
silty, fine- to coarse-grained sand				
		30		
coarse- to very coarse-grained sand				
		40		
coarse- to very coarse-grained sand with minor silt			grout to surface / crushed rock / crushed rock / grout to surface	
coarse- to very coarse-grained sand with minor clay		50		
		60		
coarse-grained sand, cemented zones				
		70		
coarse sand and gravel, heavy cementation, minor clay				
		80		
coarse- to very coarse-grained sand				
		90		
silty clay with medium sand				
coarse-grained sand, some siltstone				
		100		

FIGURE D-8
WELL LOG, WELL LI-06
WILLIAMS AFB

Page 1 Of 1

WELL NO. LI-06

Project Name Williams IRP No. 104163M Logged By [redacted]

Site LFSA Checked By [redacted]

Drilling Method Mud Rotary Date 3/6/87

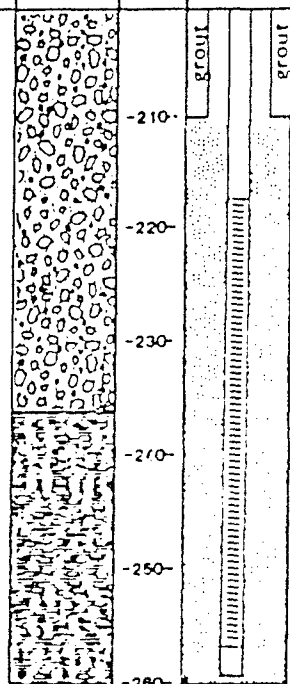
Geologic Description	Graphic Log	Depth (ft.)	Well Design	Remarks
very coarse-grained sand, minor silty clay				
		-110-		
clay and silt, minor coarse-grained sand				
		-120-		
very coarse sand with interbedded clay				
very coarse-grained sand and gravel				
		-130-		
silty, medium- to coarse-grained sand				
		-140-		
coarse-grained sand			grout crushed rock crushed rock grout	
		-150-		
coarse-grained sand				
		-160-		
very coarse-grained sand and gravel, minor clay interbeds		-170-		
very coarse-grained sand and gravel, minor clay interbeds		-180-		
		-190-		
		-200-		

FIGURE D-8
WELL LOG, WELL LI-06
WILLIAMS AFB (CONTINUED)

Page 2 Of 2

WELL NO. LI-06

Project Name	Williams IRP	No.	10416M
Logged By	[redacted]	Checked By	[redacted]
Site	LFSA	Date	3/6/87
Drilling Method	Mud Rotary		



Geologic Description	Graphic Log	Depth (ft.)	Well Design	Remarks
		-210-		
very coarse-grained sand and gravel, no clay				
		-220-		
very coarse-grained sand and gravel		-230-		
		-240-		
sandy clay, minor silt		-250-		
		-260-		
		-270-		
		-280-		
		-290-		
		-300-		

FIGURE D-8
WELL LOG, WELL LI-06
WILLIAMS AFB (CONTINUED)

Page 3 Of 3

APPENDIX E

EDWARDS AFB CA

TABLE E-1. OBSERVED FUEL THICKNESS AND DEPTH TO H_2O TABLE READINGS, 1989-1990, EDWARDS AFB CA.

	Well 1 Fuel Thickness	Well 3 Fuel Thickness	Well 7 Fuel Thickness
1989	cm	cm	cm
8 Sept	6.7	1.8	17.0
15 Sept	6.1	1.8	17.4
22 Sept	5.8	1.5	17.0
30 Sept	6.1	1.8	17.0
1990			
13 Apr	10.7	3.0	12.2
20 Apr	11.3	4.0	30.5
27 Apr	11.9	3.6	32.3
4 May	12.7	3.8	61.0
11 May	11.9	6.7	31.7
16 May	12.5	3.7	32.9
28 May	11.4	4.6	34.1
24 August	24.0	8.5	37.0
31 August	24.0	11.0	38.0
15 September	24.0	15.0	38.0
27 September	23.0	16.0	38.0
	Average	Average	Average
	13.5	5.8	30.3
	low	low	low
	5.8	1.5	12.2
	high	high	high
	24.0	16.0	61.0

	Depth to Water	Depth to Water	Depth to Water
1989	cm	cm	cm
8 Sept	1070	1082	1122
15 Sept	1070	1082	1122
22 Sept	1070	1082	1122
30 Sept	1070	1082	1122
1990			
13 Apr	1088	1097	1126
20 Apr	1088	1097	1143
27 Apr	1091	1097	1148
4 May	1092	1100	1146
11 May	1092	1100	1150
16 May	1094	1100	1150
28 May	1094	1103	1152
24 August	1113	1115	1163
31 August	1114	1118	1165
15 September	1115	1120	1165
27 September	1114	1122	1165
	Average	Average	Average
	1092	1100	1144

Figure E-1. Edwards AFB Site 17, Well 1
Fuel Thickness & H20 table depths

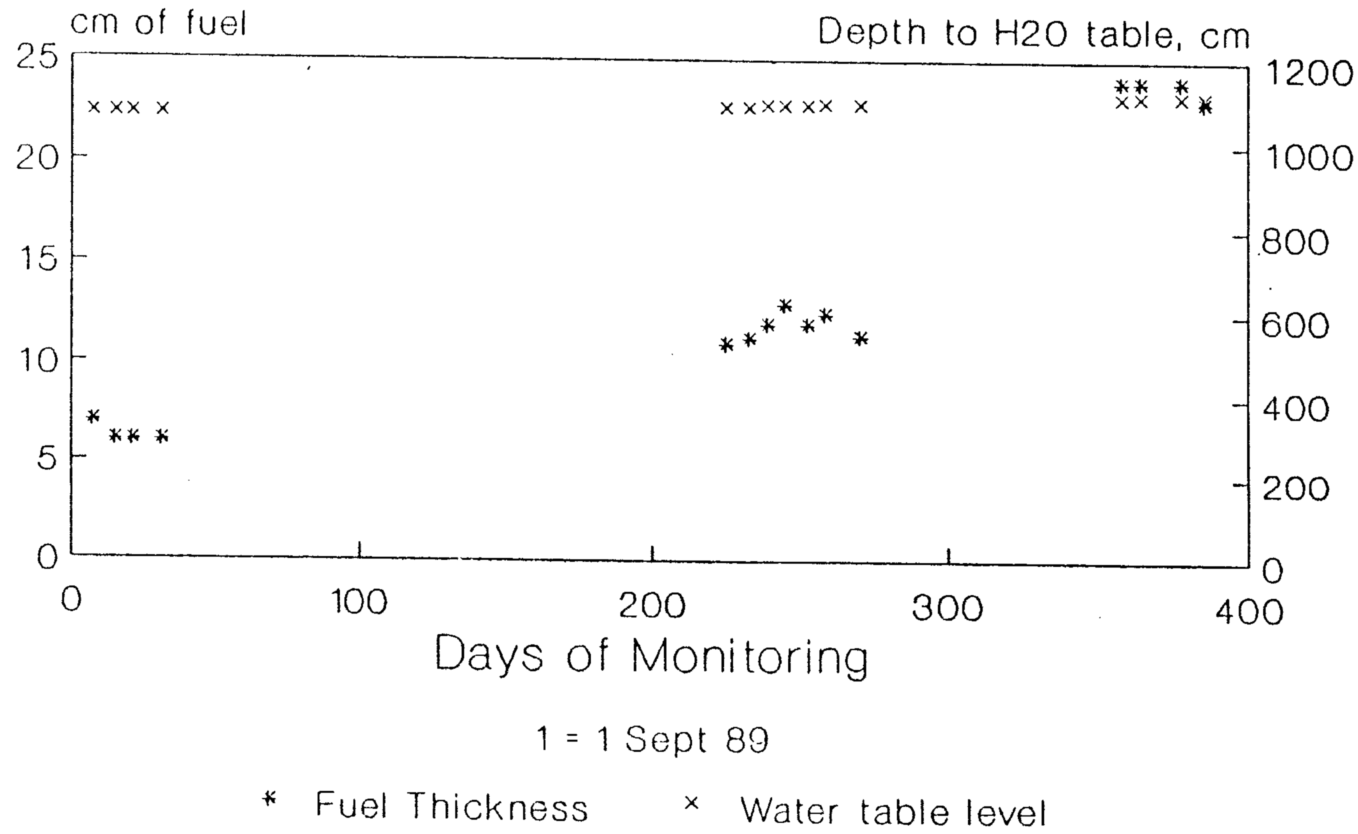


Figure E-2. Edwards AFB Site 17, Well 3
Fuel Thickness & H20 table depths

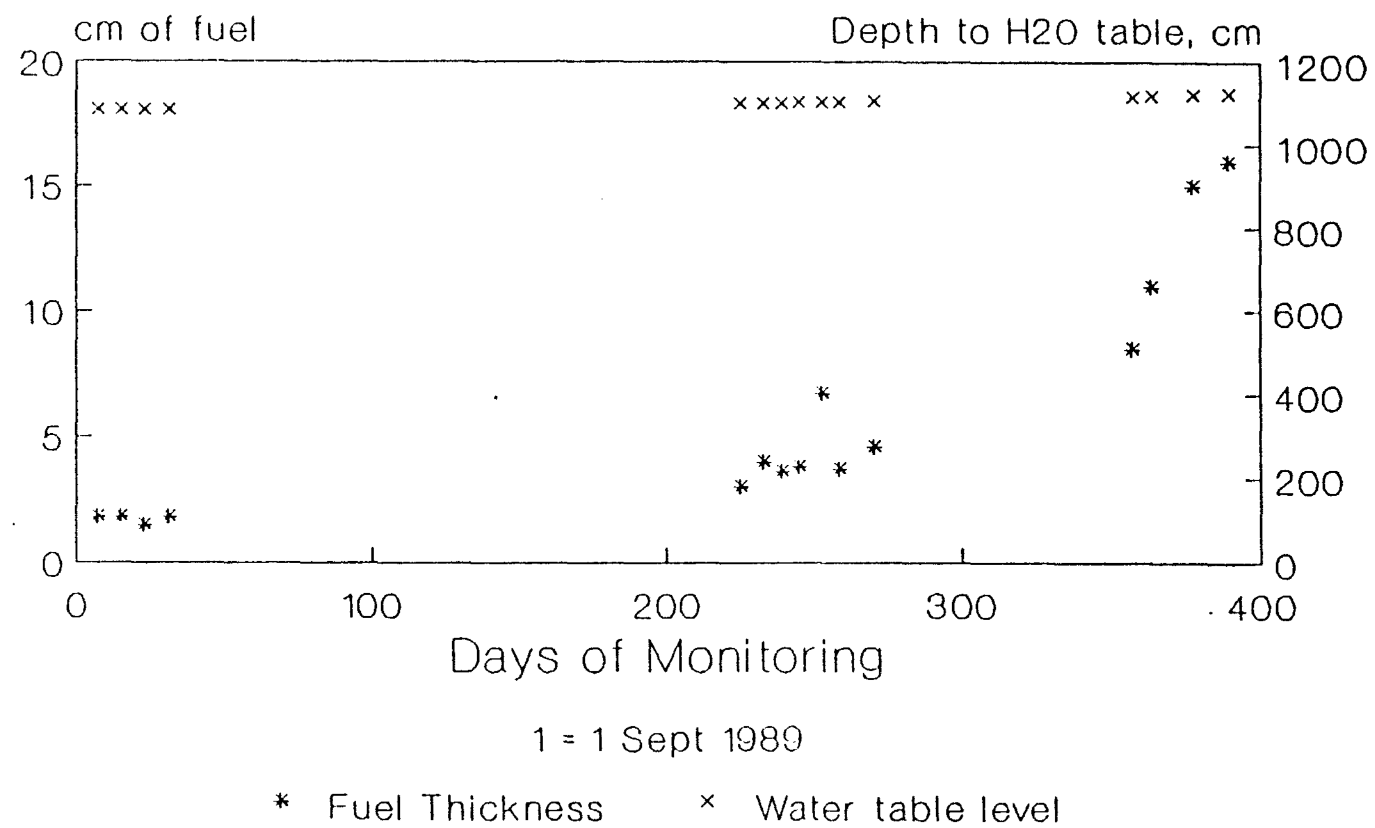
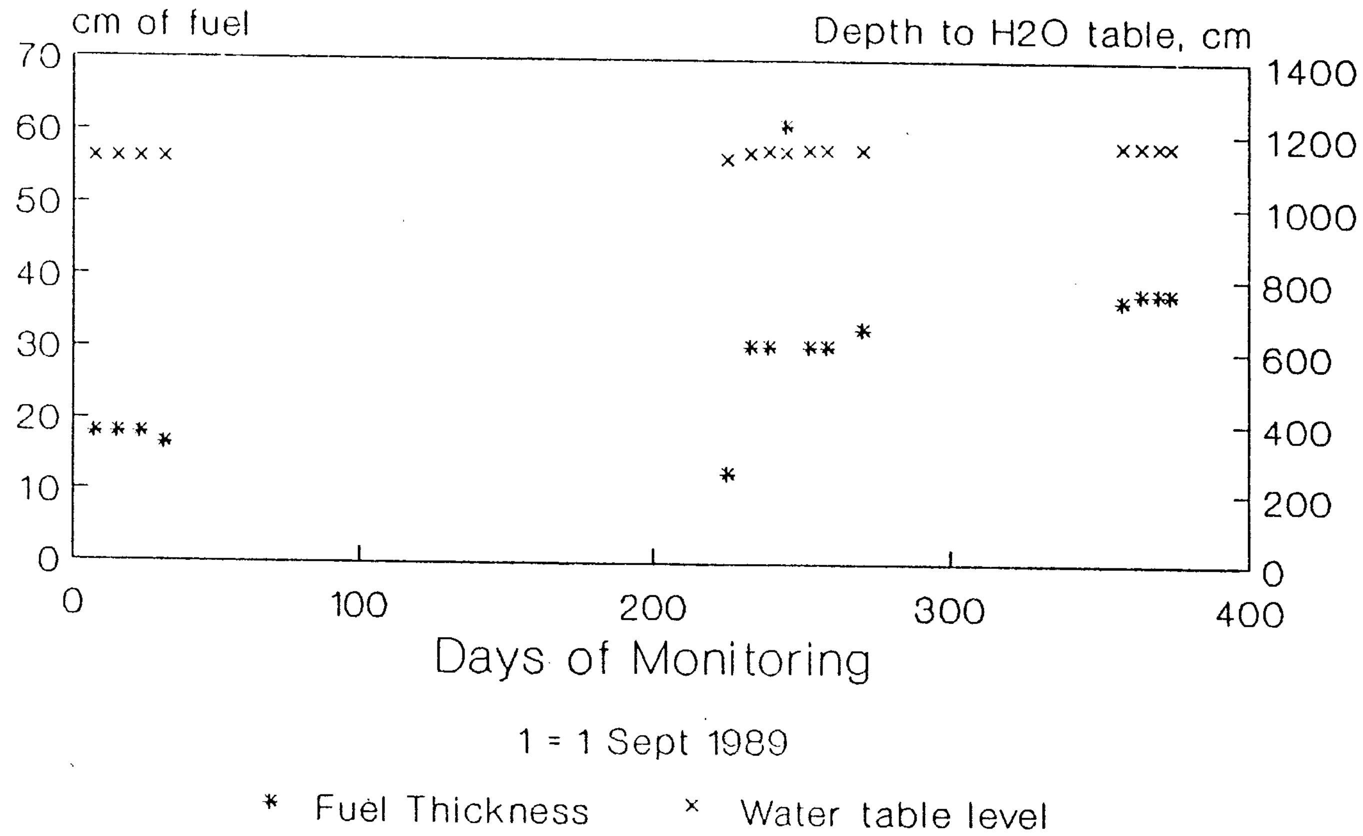


Figure E-3. Edwards AFB Site 17, Well 7
Fuel Thickness & H20 table depths



DRILLING RECORD

From: 1986 Edwards AFB IRP Report

WELL ID: 14C4-3 17-3	DRILLING STARTED: 6/29/85
LOCATION: SITE 17	DRILLING COMPLETED: 6/29/85
PROJECT NO: 56205	DRILLING METHOD: AUGER
DRILLER: [redacted]	SAMPLING METHOD: Split Spoon
LOGGER:	STATIC WATER LEVEL: 34.5
GEOLOGIST: [redacted]	WATER LEVEL DATE: 6/29/85
SIGNATURE:	WATER LEVEL DATUM: GROUND SURFACE

DEPTH IN FEET BELOW G.S.	SAMPLER BLOWS	PERCENT RECOVERY	SAMPLE ID	SAMPLE DESCRIPTION	NOTES
0				ASPHALT	
5	14/35	60		QUARTZ, f-vc SAND AND GRAVEL, brn - red brn & tan (FILL) (MOIST)	HNu (-)
10	9/85	70		QUARTZ, f-c SAND brn w/ brn grey-grn CLAY (MOIST)	HNu (-)
15	4/41	70		QUARTZ, f-vc SAND AND GRAVEL w/ Rx frags (MOIST)	HNu (-)
20	4/109	70		SAME AS ABOVE	HNu (4)
25	3/26	80		QUARTZ, f-c brn - tan - red brn w/ gray clay (MOIST) ([Clay; cobble @ 26)	HNu (8-15)

FIGURE E-4
WELL LOG, WELL 17-3
EDWARDS AFB CA

DRILLING RECORD

17-3

DEPTH IN FEET BELOW L.S.	SAMPLER BLOWS	PERCENT RECOVERY	SAMPLE ID	SAMPLE DESCRIPTION	NOTES
30	4/37	80		QUARTZ, F-C SAND, RED BRN - BRN W/ GRAVEL. QTZ VF TAN SAND (29 30)	HNu (-)
35	5/21	90		QUARTZ, VF TAN SAND; 33-34, QUARTZ VF CLAYEY SAND RED BRN (MOIST TO WET) ORGANIC ODORS.	HNu (+)
40	7/31	90		QUARTZ, F-MED GRAINED SAND, BRN TO RED TAN, BRN, 38-39, QTZ, F-M SAND GRAY-GREEN 39 40. STRONG FUEL ODORS (WET).	HNu (+)
45	5/100 10"	80		QTZ, F-C GRAINED SAND, BRN TO GRAY-GREEN 43-44; F-M SAND 44-44.5, CLAYEY SI 44.5-45 TOP OF WEATHERED RX (GRANITE) ORGANIC ODORS WET	
47 35				MACHINE REFUSAL 47 35	
50					
55				WELL CONSTRUCTION SCREEN 47 35 - 27.35. CASING 27.35 - LS SAND 47.35 - 25.35 BENTONITE 25.35 - 23 35 CEMENT GROUT 23.35 - LS	
60					

FIGURE E-4
WELL LOG, WELL 17-3
EDWARDS AFB CA (CONTINUED)

DRILLING RECORD

From: 1986 Edwards AFB IRP Report

WELL ID: 1404-1 . 17-1	DRILLING STARTED: 28 JUNE 1985
LOCATION: SITE 17	DRILLING COMPLETED: 28 JUNE 1985
PROJECT NO: 56205	DRILLING METHOD: AUGER
DRILLER: [redacted]	SAMPLING METHOD: SPLIT SPOON
LOGGER:	STATIC WATER LEVEL: 34.4 FT
GEOLOGIST: [redacted]	WATER LEVEL DATE: 29 JUNE 1985
SIGNATURE:	WATER LEVEL DATUM: GROUND SURFACE

DEPTH IN FEET BELOW L.S.	SAMPLER BLOWS	PERCENT RECOVERY	SAMPLE ID	SAMPLE DESCRIPTION	NOTES
0				ASPHALT AT SURFACE CLAYEY SAND, BROWN	MOIST
3					
5	10/40	70%		QUARTZ, FINE TO COARSE SAND w/ SOME CLAY BROWN w/SOME GRAVEL (fill) POORLY SORTED	HNu (-)
10	10/45	90%		QUARTZ, f-c SAND w/ SOME GREY CLAY, BROWN TO TAN, POORLY SORTED	HNu (-)
15	9/33	70		QUARTZ, F-C SAND w/ SOME GREY-BRN CLAY AND GRAVEL, BRN TO YELLOW TAN (MOIST) POORLY SORTED	HNu (-)
20	8/49	70		QUARTZ, f-C SAND, BRN. RED BRN - TAN (MOIST) w/ CX FRAG, (MICA) (COBBLE : CLAY ± 22')	HNu (-)
25	? 40	90		QUARTZ, f-c SAND w/ BROWN CLAY (MOIST) w/ RX FRAG	HNu (-)
30					

FIGURE E-5
WELL LOG, WELL 17-1
EDWARDS AFB CA

DRILLING RECORD

17-1

DEPTH IN FEET BELOW L.S.		SAMPLER BLOWS	PERCENT RECOVERY	SAMPLE ID	SAMPLE DESCRIPTION	NOTES
30		8/77	90		QUARTZ, F-VC SAND AND GRAVEL, BRN TO RED BRN W/ RK FRAG, MOIST, FAINT ORGANIC ODORS,	HNU - NO READING
35	∇	4/47	80		SAME AS ABOVE, STRONG ORGANIC ODORS. WET AT 34'	HNU = 5ppm AT HOLE 15ppm
40		4/42	90		QUARTZ, VF-MED, WELL ROUNDED, RED BRN TO GRN AND DK GREY W/ FINE GREY CLAY, STRONG ORGANIC ODORS (WET)	
45		7/113	95		QUARTZ, FN-CS, BRN-GREEN W/ GREEN CLAY (44-45 WEATHERED GRANITE, STRONG ORGANIC ODORS)	
47.8					MACHINE REFUSAL	
50						
55					1404-1 WELL CONSTRUCTION SCREEN 47.8 - 27.8 (20) CASING 27.8 - LS (27.8)	
				11 bags	SAND 47.8 - 25.8 (22.4)	
60				1 bucket	BENTONITE 25.8 - 23.8 (2.4)	
					CEMENT GROUT 23.8 - LS	
65						

FIGURE E-5
WELL LOG, WELL 17-1
EDWARDS AFB CA (CONTINUED)

DRILLING RECORD

From: 1986 Edwards AFB IRP Report

WELL ID:	1404-7 17-7	DRILLING STARTED:	7/9/85
LOCATION:	SITE 17	DRILLING COMPLETED:	7/10/85
PROJECT NO:	56205	DRILLING METHOD:	AUGER
DRILLER:		SAMPLING METHOD:	SPLIT SPOON
LOGGER:		STATIC WATER LEVEL:	
GEOLOGIST:		WATER LEVEL DATE:	
SIGNATURE:		WATER LEVEL DATUM:	

DEPTH IN FEET BELOW L.S.	SAMPLER BLOWS	PERCENT RECOVERY	SAMPLE ID	SAMPLE DESCRIPTION	NOTES
0					
5	10/40	50		QUARTZ, FN CLAYEY SAND, BRN W/ TRACE CO SAND (FILL) (MOIST)	
10	23/92	60		CLAYEY SAND TO SANDY CLAY, BRN TO GREY WHITE W/ TRACE CO SAND (MOIST)	
15	4/42	80		QUARTZ, VF-CO SAND AND GRAVEL, W/ BRN CLAY (MOIST)	
20	3/74	70		QUARTZ, F TO CO SAND AND GRAVEL W/ BRN CLAY AND 2X FRAGS (MOIST) [cobbles at 22', hd dry clay - difficult to drill (CALCITE LENS?)]	
25	9/49	70		QUARTZ, F-C SAND AND GRAVEL W/ BRN AND WHITE CLAY W/ STRINGERS OF HD GREY-WHITE CLAY (V. MOIST)	

FIGURE E-6
WELL LOG, WELL 17-7
EDWARDS AFB CA

DRILLING RECORD

(17-7)

DEPTH IN FEET BELOW L.S.	SAMPLER BLOWS	PERCENT RECOVERY	SAMPLE ID	SAMPLE DESCRIPTION	NOTES
30	7/78	90		Clay, light brn to white w/ stringers of calite? (moist) [ls rx frags at 31 w/ some brn clay]	
35	12/32	90		Clay, lt brn (sandy clay) organic odors (v moist)	
40	9/50	60		Quartz, f-c sand, grn-brn or grey grn, strong fuel odors (wet)	
45	8/88	80		Quartz, f-c sand grey green w/ weathered rx at 45 (white) organic odors (wet)	
49.2				Machine Refusal 49.2	
50					
55				Well Construction Screen 49.2 - 29.2 (20') Casing 29.2 - LS Sand 49.2 - 27.2 Bent. 27.2 - 25.2 Cement Grout 25.2 - LS	

FIGURE E-6
WELL LOG, WELL 17-7
EDWARDS AFB CA (CONTINUED)

APPENDIX F

COLUMBUS AFB MS

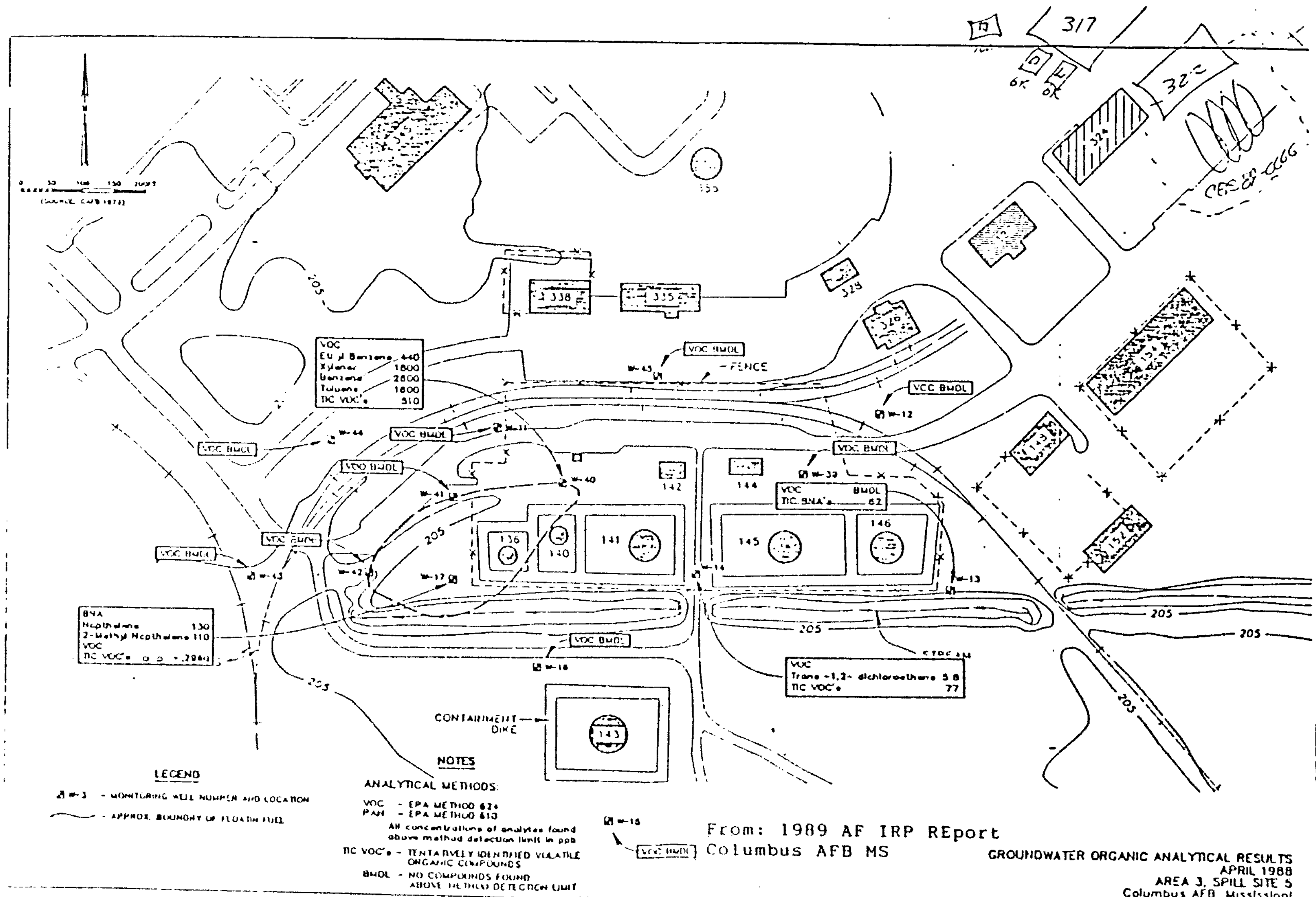


FIGURE F-1
AREA 3, SPILL SITE 5
COLUMBUS AFB MS

TABLE F-1. OBSERVED FUEL THICKNESS READINGS, COLUMBUS AFB MS.

Columbus AFB MS 1989	Well W-17 Fuel Thickness cm	Well W-41 Fuel Thickness cm	Well W-42 Fuel Thickness cm
25 May	108	46	24
2 June	91	52	24
9 June	112	19	20
16 June	112	9	21
23 June	109	37	30
30 June	109	6	34
21 July	112	24	33
28 July	109	24	39
11 August	107	51	48
25 August	105	49	73
8 September	105	48	49
15 September	105	49	48
29 September	108	45	41
6 October	105	45	45
27 October	101	42	50
1990			
2 March	134	14	61
9 March	116	12	74
25 May	101	39	86
	Average	Average	Average
	108	34	44
	low	low	low
	91	6	20
	high	high	high
	134	52	86

TABLE F-2. OBSERVED DEPTH TO WATER READINGS, COLUMBUS AFB MS.

Columbus AFB MS	Well W-17 Depth to Water cm	Well W-41 Depth to Water cm	Well W-42 Depth to Water cm
1989			
25 May	684	274	195
2 June	688	285	201
9 June	680	243	180
16 June	678	232	179
23 June	683	262	197
30 June	686	235	203
21 July	682	249	194
28 July	685	249	208
11 August	689	285	222
25 August	695	290	226
8 September	692	293	229
15 Sept	691	291	226
29 Sept	682	280	209
6 October	680	270	213
27 October	681	286	227
1990			
2 March	667	206	187
9 March	672	217	209
25 May	679	269	244
	Average 683	Average 262	Average 208

Figure F-2. Columbus AFB MS Well 17
Fuel Thickness & H20 table depths

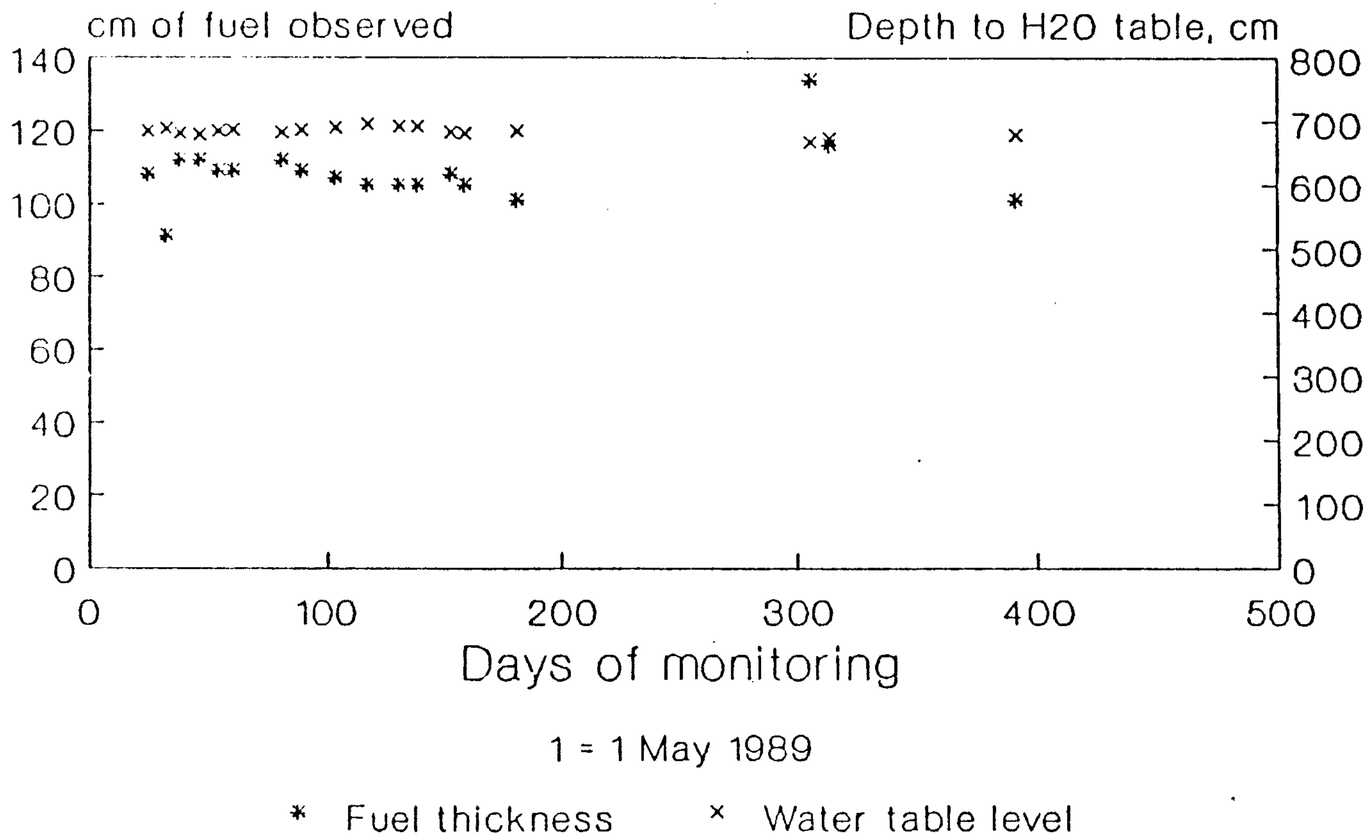


Figure F-3. Columbus AFB MS Well 41
Fuel Thickness & H20 table depths

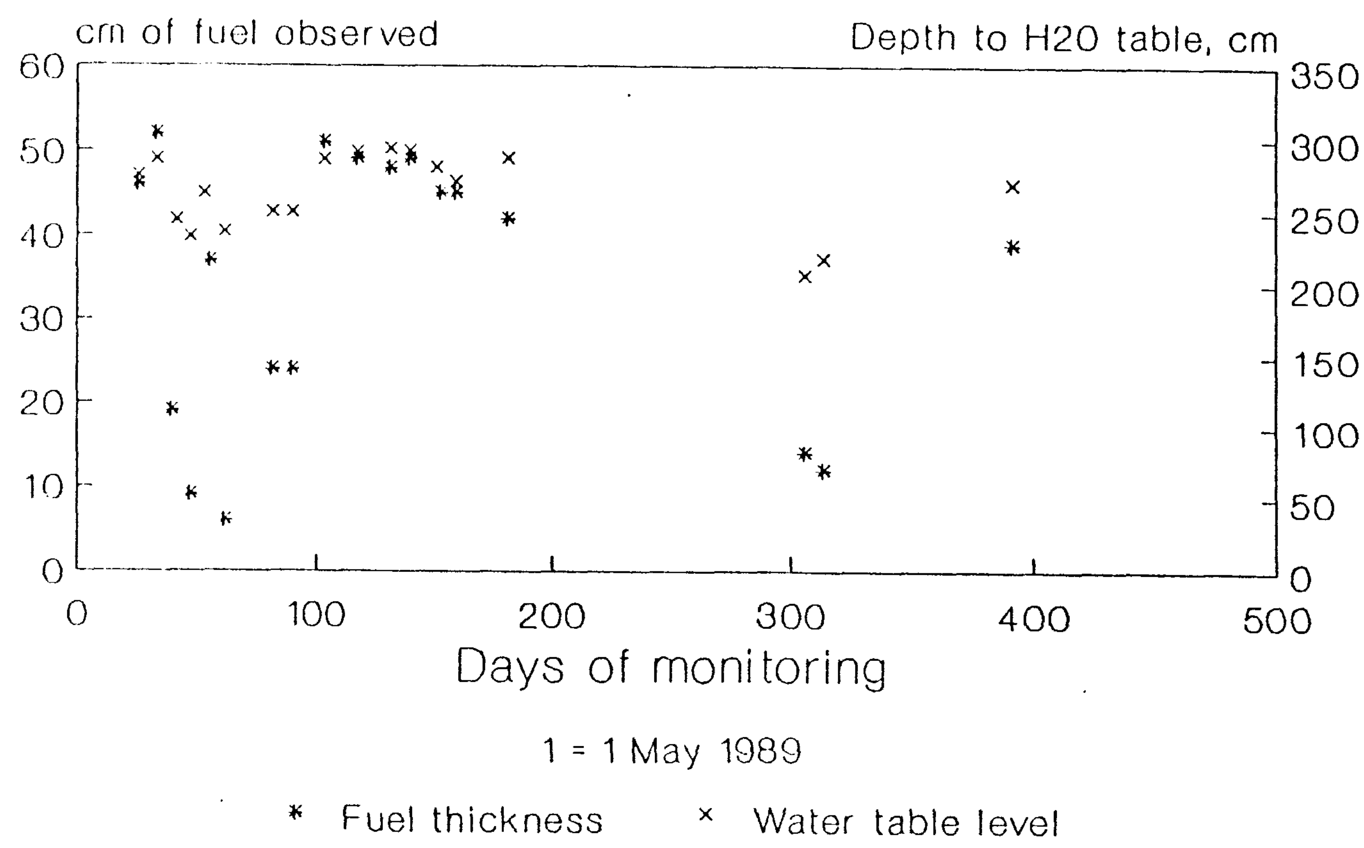
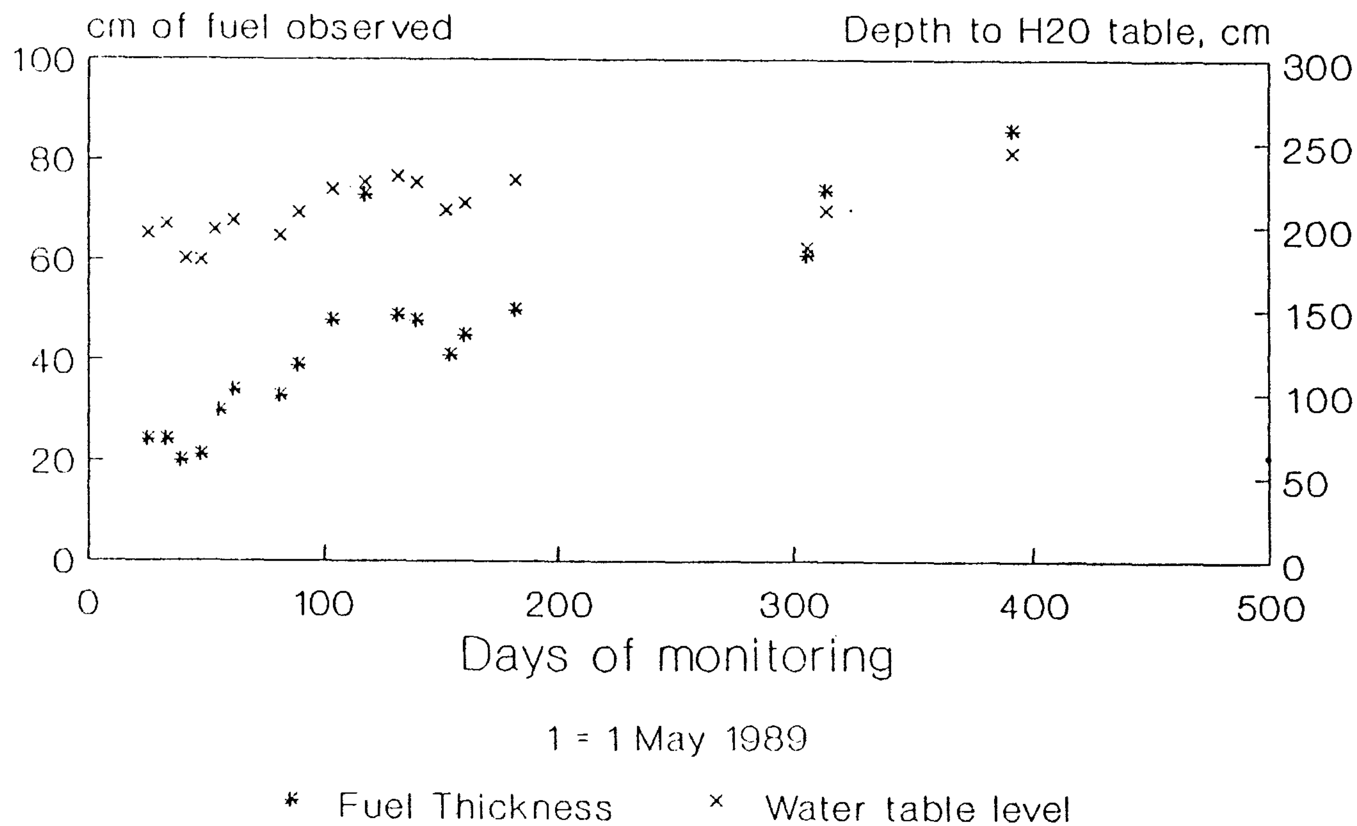


Figure F-4. Columbus AFB MS Well 42
Fuel Thickness & H20 table depths



From: 1989 AF IRP Report: Columbus AFB MS

PROJECT NUMBER MG22751.40 | BORING NUMBER W-17, W-46 SHEET 1 OF 2

SOIL BORING LOG

PROJECT COLUMBUS AFB, RT LOCATION SS-5, AREA 3

ELEVATION 207.90 (ft. msl) DRILLING CONTRACTOR [redacted]

DRILLING METHOD AND EQUIPMENT HOLLOW STEM AUGER / MOBILE B-56

WATER LEVEL AND DATE 188.35' (msl) 4/13/88 START 3/13/88 FINISH 3/13/88 LOGGER [redacted]

DEPTH BELOW SURFACE (FT)	SAMPLE: INTERVAL	SAMPLE: TYPE AND NUMBER	SAMPLE: RECOVERY (IN)	STANDARD PENETRATION TEST RESULTS 6"-6" 6"-6"	SOIL DESCRIPTION: SOIL NAME, COLOR, MOISTURE CONTENT, RELATIVE DENSITY OR CONSISTENCY, SOIL STRUCTURE, MINERALOGY, USCS GROUP SYMBOL	SYMBOLIC LOG	COMMENTS: DEPTH OF CASING, DRILLING RATE, DRILLING FLUID LOSS, TESTS AND INSTRUMENTATION
0		S-1	22"	2-2 2-4	SANDY SILT: brown, dry, soft root material. (ML) SANDY CLAY: gray to orange, dry, stiff, slight plasticity. (CL)		Start 3/13/88 1430 Using 300lb. hammer and 3" split spoon.
		S-2	21"	3-2 12-14	- - - SILTY SAND, gray to orange, dry, dense, fine (SM)		
5		S-3	20"	5-6 5-5	- - -		LEL-O_2 = 0-20% HNu reading in borehole and breathing zone = 0ppm
		S-4	21"	3-2 2-2	- - -; moist. (SM) SILTY SAND: tan, wet, dense, fine. (SM)		
		S-5	22"	3-2 4-7	- - -; clay 9.5'-10', gray to orange. (SM-CL)		
10		S-6	23"	2-6 8-9	SILTY SAND: tan, moist, very fine changing color @ 11' to gray and orange. (SM)		CSL soil sample 1500 HNu reading in borehole and breathing zone = 0ppm
		S-7	24"	2-3 5-6	SANDY CLAY: gray to orange, moist, very stiff from 11'-12', slight plasticity. (CL)		
15		S-8	24"	3-9 16-44	SILTY SAND: tan, moist, very fine, soft sandy clay, very stiff. (SM-CL) SAND: gray, dense, fine to medium, fine gravel > 10% (SP)		CSL soil sample 1530
		S-9	18"	16-49 57	- - -; wet gravel increasing, strong odor. (SP)		Refusal 17.5'
		S-10	20"	7-30 44-48	- - -; wet. (SP)		LEL-O_2 = 0-21% HNu reading in borehole = 70ppm in breathing zone = 0ppm
20		S-11	23"	9-18 17-18	SAND AND GRAVEL WITH SILT: gray with varied color gravel pebbles to cobbles, sand >20% (GM)		
		S-12	22"	9-14 16-19	- - -; odor. (GM)		LEL-O_2 = 0-21% HNu reading in borehole = 50ppm in breathing zone = 1ppm
25		S-13	23"	6-7 12-16	- - -; slight odor. (GM)		
		S-14	23"	4-8 7-14	- - -; odor. (GM)		
30		S-15	23"	17-8 12-19	- - -; odor. (GM) SAND: orange to tan, dense, fine to medium, small clay lenses. (SP)		

H_2O + fuel

NOTE: SOIL DESCRIPTIONS ON THIS LOG ARE A SUMMARY OF FIELD LOGS, VISUAL CLASSIFICATIONS OR LABORATORY TESTS [illegible]

FIGURE F-5
WELL LOG, WELL 17, W-46
COLUMBUS AFB MS

PROJECT NUMBER	BORING NUMBER
MG22751.40	W-17, W-46 SHEET 2 OF 2

SOIL BORING LOG

PROJECT COLUMBUS AFB, RI LOCATION SS-5, AREA 3

ELEVATION 207.90 (ft. msl) DRILLING CONTRACTOR [redacted]

DRILLING METHOD AND EQUIPMENT HOLLOW STEM AUGER / MOBILE B-56

WATER LEVEL AND DATE 188.35' (msl) 4/13/88 START 3/13/88 FINISH 3/13/88 LOGGER [redacted]

DEPTH BELOW SURFACE (FT)	SAMPLE			STANDARD PENETRATION TEST RESULTS	SOIL DESCRIPTION	SYMBOLIC LOG	COMMENTS
	INTERVAL	TYPE AND NUMBER	RECOVERY (IN)	6"-6" 6"-6"	SOIL NAME, COLOR, MOISTURE CONTENT, RELATIVE DENSITY OR CONSISTENCY, SOIL STRUCTURE, MINERALOGY, USCS GROUP SYMBOL		DEPTH OF CASING, DRILLING RATE, DRILLING FLUID LOSS, TESTS AND INSTRUMENTATION
30		S-16	23	9-14 14-12	- - - CLAY; orange-brown changing to dark gray, stiff. (CL)		
					BORING TERMINATED @ 32'		HNu readings on soil headspace: 15' = 25ppm 17' = 180ppm 19' = 160ppm 21' = 120ppm 23' = 120ppm 25' = 60ppm 27' = 125ppm 29' = 70ppm Install monitor well Screened interval 13.5'-28.5' Floating fuel layer ~ 1' thick 4/12/88 installed 4" monitor well, W-46 screened interval 13'-28'
35							

NOTE: [illegible]

FIGURE F-5
WELL LOG, WELL 17, W-46
COLUMBUS AFB MS (CONTINUED)

From: 1989 AF IRP Report, Columbus AFB

PROJECT NUMBER MG22751.40 | BORING NUMBER B-7, W-41 | SHEET 1 OF 1

SOIL BORING LOG

PROJECT COLUMBUS AFB RI   LOCATION SS-5, AREA 3

ELEVATION 199.05 (ft. msl)   DRILLING CONTRACTOR [redacted]

DRILLING METHOD AND EQUIPMENT HOLLOW STEM AUGER / MOBILE B-56

WATER LEVEL AND DATE 6.0' (bgs) 3/17/88   START 3/15/88   FINISH 3/15/88   LOGGER [redacted]

DEPTH BELOW SURFACE (FT)	SAMPLE: INTERVAL	SAMPLE: TYPE AND NUMBER	SAMPLE: RECOVERY (IN)	STANDARD PENETRATION TEST RESULTS 6"-6" 6"-6"	SOIL DESCRIPTION: SOIL NAME, COLOR, MOISTURE CONTENT, RELATIVE DENSITY OR CONSISTENCY, SOIL STRUCTURE, MINERALOGY, USCS GROUP SYMBOL	SYMBOLIC LOG	COMMENTS: DEPTH OF CASING, DRILLING RATE, DRILLING FLUID LOSS, TESTS AND INSTRUMENTATION
		S-1	18"	2-4 4-7	SAND; tan to gray, moist, <5% silt, fine. (SP)		Started drilling at 0700 Using 300lb hammer and 3" split spoon
		S-2	24"	3-5 8-11	- - -: gray to brown. (SP)		CSL soil sample
5		S-3	18"	6-18 23-26	SAND WITH GRAVEL; tan, moist, clean, coarse with 30% gravel 3/4" max. (SP)		
		S-4	20"	7-15 18-19	- - -: wet. (SP)		
▼		S-5	16"	8-19 16-18	GRAVEL; tan, wet, <5% silt, 5% sand, gravel 1" max. (GW)		CSL soil sample 0750 Vinyl chloride test negative
10		S-6	18"	12-9 14-16	- - -		
		S-7	24"	8-12 15-20	- - -		HNu readings in borehole and breathing zone = 0.2ppm
15		S-8	-	16-23 14-11	SAND; tan to orange, wet <5% silt, 5% gravel, fine. (SP)		
		S-9	-	6-4 7-12	- - -: gray, moist, silt lenses 1/2" every few inches, otherwise clean, medium. (SP)		HNu reading in borehole = 2ppm In breathing zone = 0.2ppm
		S-10	-	4-4 14-27	- - -: gray, fine, moist, 10% silt, 10% gravel 1/2" max., few clay lenses. (SP)		HNu reading in borehole = 0.2ppm
20					BORING TERMINATED @ 20'		Installed temporary casing sampled groundwater. pulled casing and grouted to surface (4/11/88 W-41) Installed monitor well screened interval [illegible] HNu readings on soil headspace. 1' = 3.2ppm 3' = 40ppm 5' = 3ppm 7' = 3ppm 9' = 20ppm 11' = 15ppm 13' = 1ppm

FIGURE F-6
WELL LOG, WELL B-7, W-41
COLUMBUS AFB MS

From:1989 AF IRP Report Columbus AFB MS

PROJECT NUMBER	BORING NUMBER
MG22751.40	B-8, W-42 SHEET 1 OF 1

SOIL BORING LOG

PROJECT COLUMBUS AFB RI LOCATION SS-5, AREA 3

ELEVATION 195.91 (ft. msl) DRILLING CONTRACTOR [redacted]

DRILLING METHOD AND EQUIPMENT HOLLOW STEM AUGER / MOBILE B-56

WATER LEVEL AND DATE 9.0' (bgs) 3/17/88 START 3/17/88 FINISH 3/17/88 LOGGER [redacted]

DEPTH BELOW SURFACE (FT)	SAMPLE: INTERVAL	SAMPLE: TYPE AND NUMBER	SAMPLE: RECOVERY (IN)	STANDARD PENETRATION TEST RESULTS 6"-6" 6"-6"	SOIL DESCRIPTION: SOIL NAME, COLOR, MOISTURE CONTENT, RELATIVE DENSITY OR CONSISTENCY, SOIL STRUCTURE, MINERALOGY, USCS GROUP SYMBOL	SYMBOLIC LOG	COMMENTS: DEPTH OF CASING, DRILLING RATE, DRILLING FLUID LOSS, TESTS AND INSTRUMENTATION
		S-1	20"	10-12 7-4	GRAVEL; red to brown, moist, 20% silt, 20% sand. (FILL)		Using 300lb hammer and 3" split spoon.
		S-2	22"	3-2 5-7	CLAY; gray, moist, 20% silt. (CL)		
5		S-3	24"	3-4 4-10	- - -; orange to tan fine sand, brown organic areas. (CL)		Vinyl chloride test negative 1220 HNu reading in borehole = 20ppm in breathing zone = 2ppm CSL soil sample 1240
		S-4	24"	3-5 6-7	CLAY; gray, moist, 20% silt. (CL)		
		S-5	24"	3-6 10-12	SAND; gray to tan, wet, fine to medium. (SP)		
10		S-6	24"	4-9 10-16	- - -; medium grain. (SP)		HNu reading in borehole = 15ppm in breathing zone = 2ppm CSL soil sample 1240
		S-7	24"	7-20 20-21	GRAVEL; tan, wet, 10% sand, 3/4" max. size, no fines. (GW)		
15		S-8	20"	5-18 18-14	- - -		CSL soil sample 1255 HNu reading in borehole = 3ppm in breathing zone = 1ppm
		S-9	-	4-7 12-10	- - -; <5% sand. (GW)		
20		S-10	-	4-2 5-9	SAND; tan with black grains, wet, fine, no fines (SP)		
					BORING TERMINATED @ 20'		Installed temporary casing, pulled casing and grouted to surface. 3/29/88 (W-42) Free product @ 9ft. Installed monitor well screened interval 3'-18' HNu readings on soil headspace, 7' = 3ppm 9' = 150ppm 11' = 170ppm 13' = 100ppm 15' = 100ppm 17' = 40ppm 19' = 2ppm

NOTE: SOIL DESCRIPTIONS ON THIS LOG ARE A SUMMARY OF FIELD LOGS, VISUAL CLASSIFICATIONS OR LABORATORY TESTS [illegible]

FIGURE F-7
WELL LOG, WELL B-8, W-42
COLUMBUS AFB MS